

P 2mif
SPACE
DIVISION

OCTOBER 1973

NASA CR-132342 - Vol. I

DEVELOPMENT

OF A

HOUSEHOLD WASTE TREATMENT SUBSYSTEM

BY

THOMAS M. GRESKO

AND

ROBERT W. MURRAY

FINAL REPORT

PREPARED UNDER CONTRACT NO. NAS1-11770

N74-16838

(NASA-CR-132342-Vol-1) DEVELOPMENT OF A
HOUSEHOLD WASTE TREATMENT SUBSYSTEM,
VOLUME 1 Final Report (General Electric
Co.) . 68 p HC
CSCI 06I

Unclas
G3/05 29641

General Electric Company
Space Division
Valley Forge Space Center
P. O. Box 8555
Philadelphia, Pennsylvania 19101

GENERAL  ELECTRIC

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
US Department of Commerce
Springfield, VA. 22151



FOREWORD

This document was prepared by the General Electric Company under contract NAS1-11770, "Domestic Water and Waste Treatment Subsystem", for the Langley Research Center of the National Aeronautics and Space Administration. The effort was administered under the technical direction of Mr. John B. Hall, Jr. as Technical Manager.

Preceding page blank

CONTENTS

	<u>Page</u>
1.0 SUMMARY	6
2.0 INTRODUCTION	8
2.1 Subsystem Requirements	8
2.2 Baseline Concepts.	9
2.3 Scope	11
3.0 TECHNICAL DISCUSSION	11
4.0 SUBSYSTEM AND COMPONENT DESCRIPTION	14
4.1 Subsystem Operation.	14
4.2 Subsystem Component Descriptions	18
4.2.1 Blower	18
4.2.2 Heat Exchangers	19
4.2.3 Evaporator/Condenser.	20
4.2.4 Catalytic Oxidizer	22
4.2.5 Grinder	25
4.2.6 Sedimentation Tank	26
4.2.7 Holding Tank	29
4.2.8 Incinerator	29
4.2.9 Pumps	32
4.2.10 Recovered Water Tank	34
4.3 Subsystem Controls	34
4.3.1 Catalytic Oxidizer	34
4.3.2 Incinerator	36
4.3.3 Holding Tank Liquid Level	36
4.3.4 Auger	37
4.3.5 Grinder	37
4.3.6 Spray Chamber	37
4.3.7 Other Features	37
4.4 Instrumentation	38
4.5 Interfaces (Including Power)	39
5.0 SYSTEM TESTS AND RESULTS	44
5.1 Functional	44
5.2 Performance	46
6.0 CONCLUSIONS	67

LIST OF TABLES

<u>TABLE</u>		<u>PAGE</u>
1-1	Presently Available Methods	10
4-1	Installation Interfaces	40
4-2	Electrical Power Requirements	42
4-3	Subsystem Weight	43
5-1	Wastewater Model	47
5-2	Performance Test Data	49
5-3	Test Data After Hot Water Heater Addition	54
5-4	Microbiological Analysis	59
5-5	Affluent Chemical Analysis	60
5-6	Chemical Analysis of Effluent Water During Day #1 . .	61
5-7	Chemical Analysis of Effluent Water During Day #2 and #3	62
5-8	Output Gas Analysis	63
5-9	Performance Comparison	64
5-10	Recovered Water Comparison	65
5-11	Chemical Comparison of Affluent and Effluent of Day #2 and #3	66

LIST OF ILLUSTRATIONS

<u>FIGURE</u>		<u>PAGE</u>
1-1	Domestic Water & Waste Treatment Subsystem	7
3-1	Psychrometric Process	12
4-1	System Block Diagram	15
4-2	System Schematic	17
4-3	Blower Performance Curve	19
4-4	Domestic Water & Waste Treatment Subsystem	23
4-5	Hemispherical Head In Place On Catalyst Bed	24
4-6	Exposed Catalyst Bed	24
4-7	Grinder.	25
4-8	Sedimentation Tank	28
4-9	Water Usage Profile	30
4-10	Incinerator	32
4-11	Wiring Schematic	34
4-12	Instrumentation Location	35
4-13	Subsystem Interfaces	41
5-1	Subsystem Configuration	48
5-2	Thermocouple Locations	50
5-3	Evaporation Rate	51
5-4	Condensation Rate	52
5-5	Water Heater Addition Schematic	55
5-6	Evaporation Rate After Hot Water Heater Addition . .	56
5-7	Condensation Rate After Hot Water Heater Addition. .	57

1.0 SUMMARY

The Domestic Waste Treatment Subsystem was developed to process the daily liquid and non-metallic solid wastes provided by a family of four people. The subsystem was designed to be connected to the sewer line of a household which contained water conservation features. The system consisted of an evaporation technique to separate liquids from solids, an incineration technique for solids reduction, and a catalytic oxidizer for eliminating noxious gases from evaporation and incineration processes. All wastes were passed through a grinder which masticated the solids and deposited them in a settling tank. The liquids were transferred through a cleanable filter into a holding tank. From here the liquids were sprayed into an evaporator and a spray chamber where evaporation occurred. The resulting vapors were processed by catalytic oxidation. Water and latent energy were recovered in a combination evaporator/condenser heat exchanger. The solids were conveyed into an incinerator and reduced to ash while the incineration gases were passed through the catalytic oxidizer along with the processed water vapor. See Figure 1-1 for subsystem configuration.

This effort was implemented with a brief study to determine system applications, process rates and the most applicable waste treatment concept. Fabrication and assembly followed the design, with standard commercial parts used wherever possible. Particular emphasis was given to providing both an attractive appearance and eliminating all hazardous process conditions.

The subsystem feasibility was then proven by evaluating subsystem performance under various operating conditons.

The subsystem operated odor free, produced a clear water effluent, completely incinerated waste solids and met all contract requirements.

This page is reproduced at the back of the report by a different reproduction method to provide better detail.

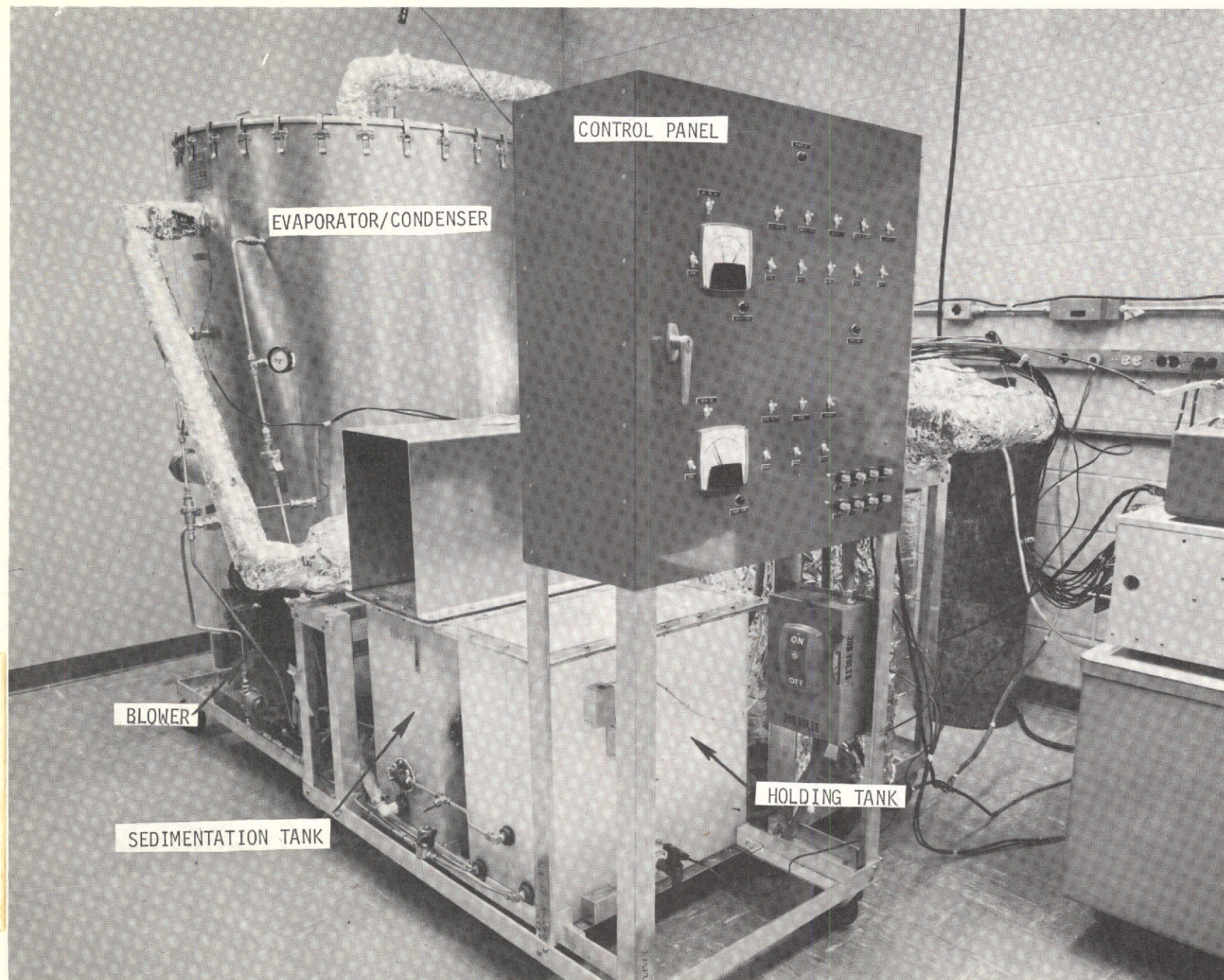


FIGURE 1-1 DOMESTIC WATER AND WASTE TREATMENT SUBSYSTEM

2.0 INTRODUCTION

During the past decade, the National Aeronautics and Space Administration (NASA) has developed techniques for processing wastes in order to support proposed extended manned space missions. Much of this technology has been integrated into the Household Waste Treatment Subsystem developed during this effort. The integrated system approach to waste management and water recovery has the possibility of solving domestic sewage problems which are either too small or remotely located for the use of municipal sewage treatment facilities.

The objectives of this program were twofold: (1) To apply NASA technology to the public sector problems and, (2) to develop an operable unit which could be utilized to demonstrate how domestic waste management problems could be solved.

This program provided for the design and development of a household waste treatment subsystem which was evaluated for processing the sewage wastes representative of a domestic household.

2.1 Subsystem Requirements

The Household Waste Treatment Subsystem was designed to fulfill the following requirements:

- (1) Operate essentially maintenance free, incorporate features for energy conservation, and generate products that did not cause environmental pollution.
- (2) Process 246 liters/day (65 gal/day) of waste liquids by an evaporation process.
- (3) Reduce 2.72 Kg/day (6 lbs/day) of waste solids by incineration.
- (4) Process water from household wastes that approached the requirements given in the United States Public Health Standards for drinking water, 1962.

- (5) Produce gases from solids reduction that approached the requirements established by the Environmental Protection Agency for Air Pollution Control.
- (6) Sufficient heat exchangers to facilitate energy conservation to reuse the latent heat of evaporation and waste heat from the incineration process.
- (7) Temperature instrumentation for operation during testing and sufficient chemical, gas and biological sampling ports provided to isolate problem areas.
- (8) Packaging to facilitate the replacement of expendables and maintenance and repair functions.

2.2 Baseline Concepts

The Household Waste Treatment Subsystem employed air evaporation for the distillation of liquid waste, incineration to reduce the volume of the solid waste and catalytic oxidation of the resulting gas/vapor effluents.

Table 1-1 lists several waste collection, water recover and solids processing methods now available. Although waste collection is not a part of the subsystem, collection is listed to show the interrelationship.

Reasons for the selected processes were as follows:

- (1) The air evaporation process represents a relatively low temperature, atmospheric pressure process. The low temperature minimizes volatiles generation and thermal losses. Operating at low pressure minimizes structural strength and liquid/gas leakage problems. Also relatively complex precision equipment, such as a vacuum pump, is not required.
- (2) In addition to reducing the solid waste volume, incineration assures that the resulting ash is sterile, odor free and asthetically acceptable during periodic removal.

WASTE COLLECTION

- COMMODES
- URINALS
- GARBAGE DISPOSALS
- TRASH DISPOSALS
- FEED LOT TRAPS
- LAUNDRY TRAPS
- SINK TRAPS
- INDUSTRIAL WASTES

WATER RECOVERY

- DISTILLATION
- CATALYTIC OXIDATION
- FILTRATION
- ELECTRODIALYSIS
- ELECTRO COAGULATION
- ION EXCHANGE
- CHARCOAL
- REVERSE OSMOSIS
- CHEMICAL TREATMENT
- CENTRIFUGATION
- FLOCCULATION
- SETTLING
- AERATION
- OZONE
- AIR EVAPORATION

SOLIDS PROCESSING

- DRYING
- INCINERATION
- WET OXIDATION
- THERMAL DECOMPOSITION
- MICROBIAL DIGESTION
- CHEMICALS

TABLE 1-1 PRESENTLY AVAILABLE METHODS

- (3) Catalytic oxidation eliminates the need for chemical or other pretreatment of the incoming sewage or similar post treatment of the recovered water to achieve high purity water. In addition, the catalytic oxidizer neutralizes any noxious/toxic gases or vapors evolved as part of the air evaporation or incineration processes.

2.3 Scope

An integrated system of the type described has direct application to domestic dwellings, Alaskan village community centers, ships, barges, pleasure craft, submarines, mobile military facilities, small stationary military facilities, oil drilling platforms, recreational vehicles, bus stops, highway rest stops, remote recreational parks, cattle feed lots, etc.

A mass produced unit would probably sell for \$2000 which, for a domestic dwelling, would compare favorably with the cost of installing a septic tank or connecting with a municipal sewage system. Presently, large sections of highly populated areas are not used because the sewage systems or the earth's drainage conditions will not permit new construction. An integrated system could solve this problem. Another instance is the Federal Standards for sewage treatment on ships plying oceans, rivers, and lakes. This mobile unit will demonstrate the applicability of the system to check numerous specialized pollution problems to proper government agencies and a variety of industrial leaders.

3.0 TECHNICAL DISCUSSION

In order to prove the thermodynamic feasibility of the subsystem, the theoretical water treatment process is mapped on a psychometric chart (Figure 3-1) and is explained as follows:

- a - b Room air enters the evaporator at 26.6°C (80°F), 100% R.H. (worst case) and leaves at 49°C (120°F), 100% R.H.

NOT REPRODUCIBLE

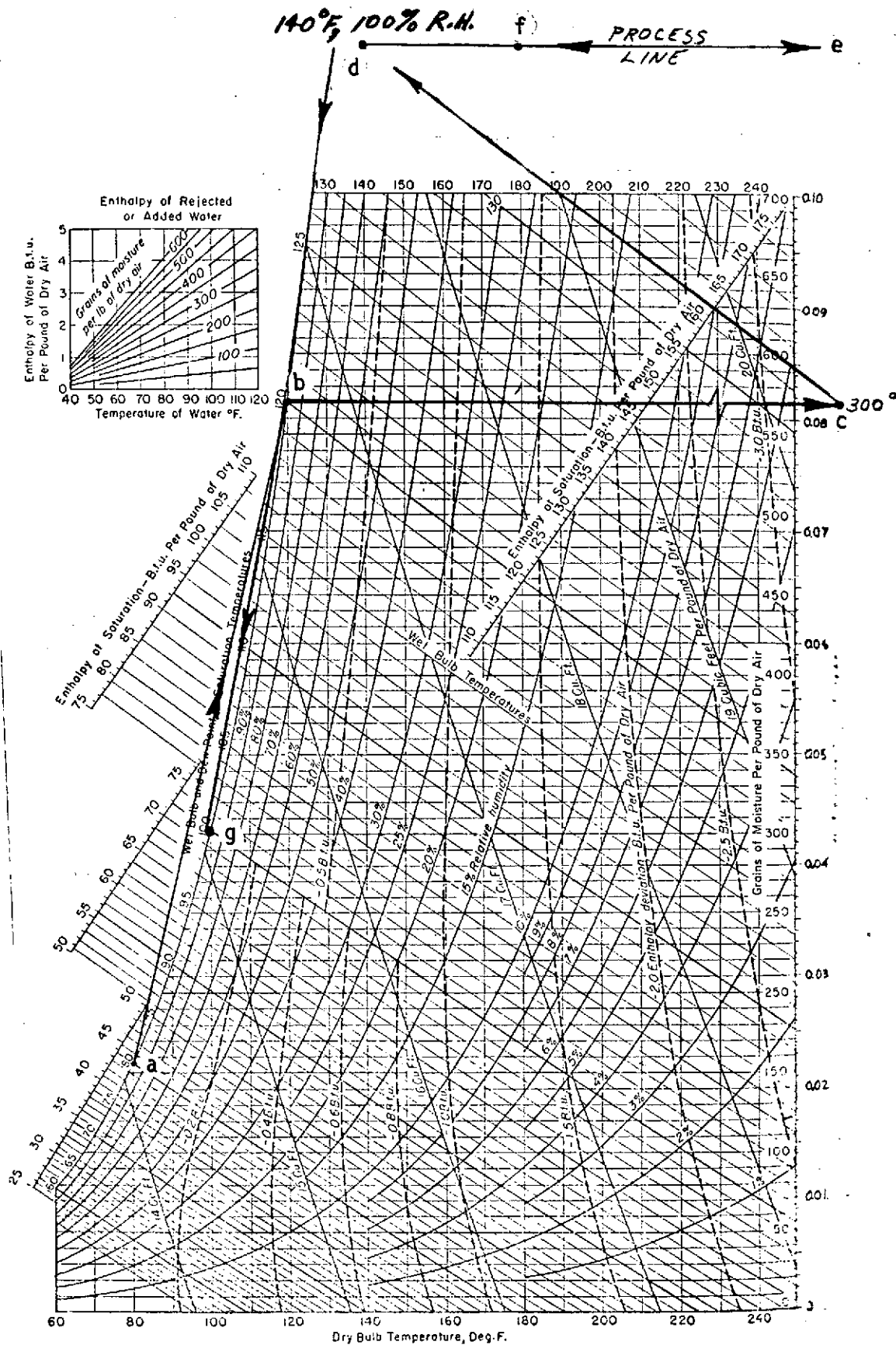


FIGURE 3-1 PSYCHROMETRIC PROCESS

- b - c Air picks up heat from the blower and the small heat exchanger and enters the spray chamber at 149°C (300°F), 5% R.H.
- c - d Air passes through the spray chambers, absorbing more moisture and leaves at 60°C (140°F) saturated.
- d - e The saturated air is then processed by passing through a recuperative heat exchanger, the catalytic oxidizer and finally enters the condenser jacket of the evaporator at 82°C (180°F) at F.
- f - g The air enters the jacket at 82°C (180°F) and leaves at 100°F, saturated.

Theoretical process rates were calculated as follows:

Liquid Evaporated

$$60^{\circ}\text{C} (140^{\circ}\text{F}), 100\% \text{ R.H.} \quad W = .152 \text{ Kg water/Kg air}$$

$$26.6^{\circ}\text{C} (80^{\circ}\text{F}), 100\% \text{ R.H.} \quad W = .022 \text{ Kg water/Kg air}$$

$$\Delta W = .130 \frac{\text{Kg water}}{\text{Kg air}}$$

$$\text{Liquid Pickup} = \Delta W \times \text{Air Flow}$$

$$= .130 \frac{\text{Kg water}}{\text{Kg air}} \times 94.6 \text{ Kg/hr air (208.5 lb/hr air)}$$

$$= 12.3 \text{ Kg Liquid (27.1 lbs Liquid)}$$

Water Condensed

$$60^{\circ}\text{C} (140^{\circ}\text{F}), 100\% \text{ R.H.} \quad W = .152 \text{ Kg water/Kg air}$$

$$38^{\circ}\text{C} (100^{\circ}\text{F}), 100\% \text{ R.H.} \quad W = .043 \text{ Kg water/Kg air}$$

$$\Delta W = .109 \frac{\text{Kg water}}{\text{Kg air}}$$

$$\text{Water Recovered} = \Delta W \times \text{Air Flow}$$

$$= .109 \frac{\text{Kg water}}{\text{Kg air}} \times 94.6 \text{ Kg/hr air (208.5 lb/hr air)}$$

$$= 10.4 \text{ Kg water (22.7 lbs water)}$$

The foregoing system theory is based on liquid water and water vapor, whereas the subsystem must also process urine and wash water. However, the use of clean water for calculations was offset by the generous safety factors applied to equipment design.

As a final comment, the liquid evaporation rate required is 12.3 Kg/hr (27 lb/hr), and as seen from the psychrometric calculations:

$$\frac{\text{Water Recovered}}{\text{Liquid Evaporated}} = \frac{10.4}{12.3} = .84$$

The theoretical efficiency of the subsystem is 84%.

4.0 SUBSYSTEM AND COMPONENT DESCRIPTION

The Household Waste Treatment Subsystem will now be described in detail beginning with the total subsystem, followed by each individual component. Figure 4-1 illustrates the total subsystem in block diagram form while Figure 4-2 shows the detailed system schematic which can be referenced during the overall subsystem description.

4.1 Subsystem Operation

Sewage wastes entered the system through a grinder which passed the liquid portion, periodically chopped the solids, and deposited both into the sedimentation tank. Liquid/solid separation occurred in the relatively undisturbed water as the solids settled to the bottom of the tank. The liquids were passed slowly into the holding tank through two cleanable filters, while the wet solids were transported to the incinerator by a motor driven auger where they were dried and reduced to ash. The ashes were removed periodically while the incinerator vapor and gas effluents were directed through the catalytic oxidizer for oxidation of noxious/toxic gases.

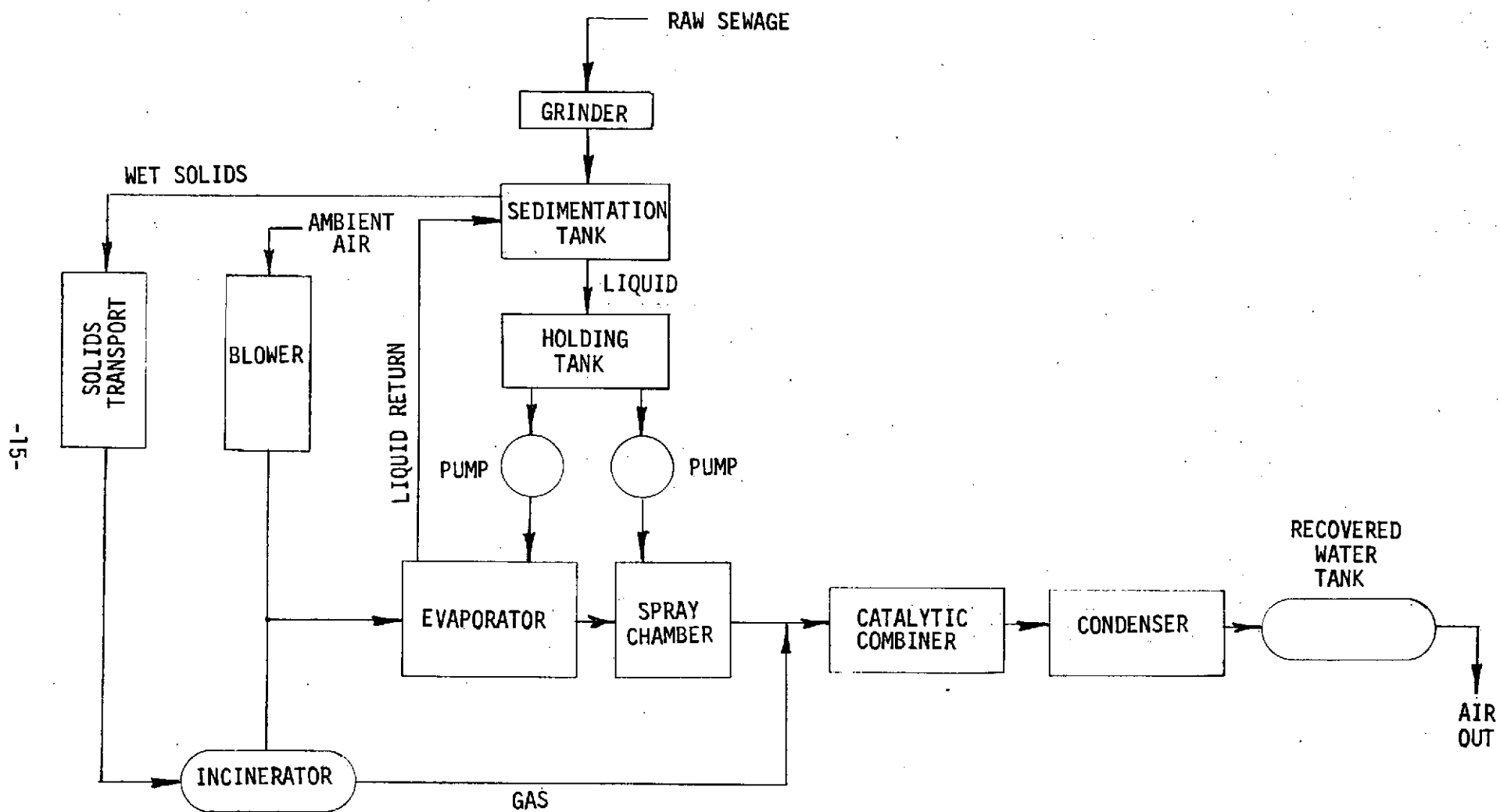


FIGURE 4-1 BLOCK DIAGRAM

Waste liquids were removed from the holding tank by two pumps which transported the liquid to the evaporator and the spray chamber for distillation. Pump #1 forced the liquid through the two atomizers in the evaporator. Each atomizer delivered liquid at 11.4 ℓ/hr^* for an operating pressure of 0.7 Kg/cm^2 (3 gal/hr at 10 psi). As the mist contacted the walls, most of the droplets were evaporated by the transfer of heat from the hot airstream in the condenser and was absorbed by the incoming dry air of the evaporator. The vapor was transferred through the low temperature heat exchanger, thus raising its temperature, and its associated vapor saturation capacity. Liquids not evaporated were returned to the sedimentation tank and recycled. The second stage of evaporation occurred in the spray chamber, where pump #2 continually recirculated liquid from a sump within the chamber through a spiral nozzle rated at 30.3 ℓ/hr at 0.7 Kg/cm^2 (8 gal/hr at 10 psi). By recirculation within the spray chamber, the liquid was able to reach the wet bulb temperature of the incoming air (140°F) with minimal heat loss. Solenoid valve SV-2 opened only to replenish the liquid in the chamber with liquid from the holding tank. Cleanable traps were provided in both liquid lines to prevent nozzle plugging.

After absorbing moisture in the spray chamber, the saturated air was transferred through the high temperature recuperative heat exchanger where it was heated by the air leaving the catalytic oxidizer on route to the small heat exchanger. The air passing through the small heat exchanger transferred a portion of its heat to the air leaving the blower and entering the evaporator chamber. The air was then transferred into the condenser jacket where moisture was removed by transferring latent heat through the evaporator wall to the cooler water inside. Gravity and airflow transported all condensate into the recovery tank as the air exited the system.

* ℓ = liters

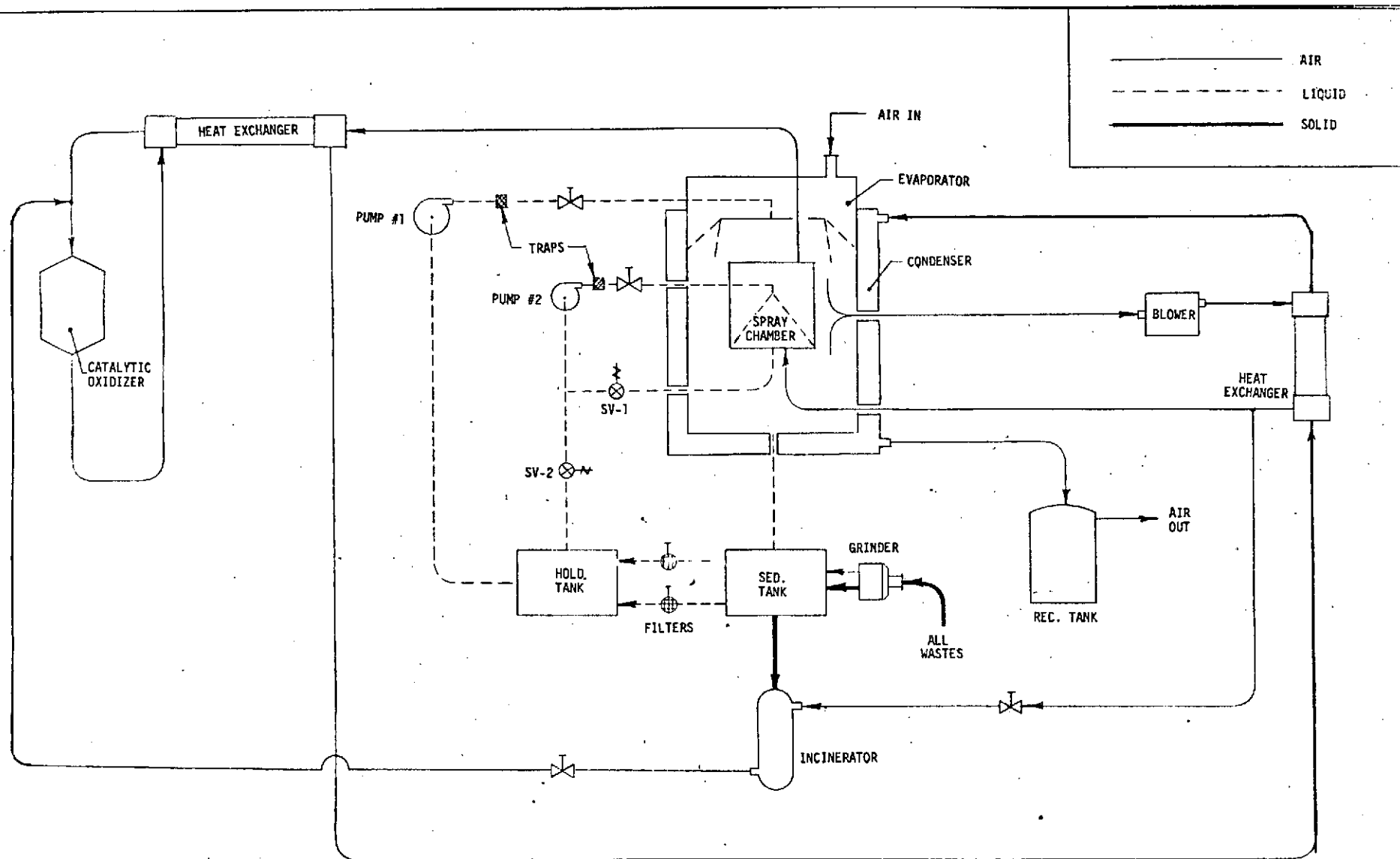


FIGURE 4-2 SYSTEM SCHEMATIC

4.2 Subsystem Component Descriptions

4.2.1 Blower

The function of the blower was to transport air through the subsystem in order to evaporate liquids and provide oxygen for incineration of the solids.

The air flow required was calculated as follows:

$$\frac{12.26 \text{ Kg of water/hr}}{0.13 \text{ Kg of water/Kg of air}} = \frac{\text{required evaporate rate}}{\text{net water pickup thru evaporator stages}} \\ \text{(See Psych. Chart)}$$

$$= 94.2 \text{ Kg of air/hr} \times 882 \frac{\ell}{\text{Kg}} \times \frac{1 \text{ hr}}{60 \text{ min}} = 1390 \ell/\text{min} \text{ (49.2 ft}^3/\text{min)}$$

where 882 ℓ/Kg is the specific volume of air at 38°C (100°F).

The pressure drops throughout the system were estimated for this air flow and are listed below:

Evaporator	7.61 cm of water	(3")
Low Temperature H.E.	5.07 cm	(2")
Spray Chamber	10.3 cm	(4")
High Temperature H.E.	10.3 cm	(4")
Catalytic Oxidizer	30.5 cm	(12")
High Temperature H.E. (Return)	10.3 cm	(4")
Low Temperature H. E. (Return)	5.07 cm	(2")
Condenser Jacket	50.7 cm	(20")
Tubing	25.4 cm	(10")

TOTAL PRESSURE DROP 155.3 cm (61 inches of water)

Thus a blower rated at 1395 ℓ/min at 155.3 cm (50 cfm and 61 inches) of water was required. Ametek/Lamb model No. 115691 "Windjammer" blower was chosen whose characteristic curve is shown in Figure 4-3.

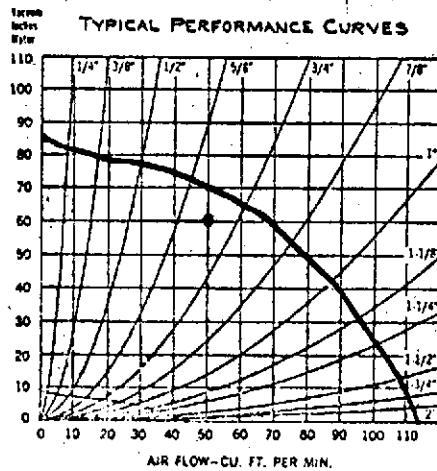


FIGURE 4-3 BLOWER PERFORMANCE CURVE

The blower is a seven stage centrifugal belt driven blower operating on 115/230 volts and 24/12 amps. Figure 4-3 shows that the blower operating point is well below its performance curve, thus assuring a safety factor and longer life capability.

4.2.2 Heat Exchangers

Energy conservation was achieved through the use of two shell and tube type heat exchangers.

The low temperature heat exchanger was used to 1) preheat air to 149°C (300°F) prior to upon entering the spray chamber and 2) to cool air entering the condenser. An overall heat transfer coefficient of 3.4 Btu/hr/°F/ft² was used to size the heat transfer needed to obtain the required temperature differences. From this, the area was calculated to be 2.23 m² (24 ft²) while the heat exchanger chosen

contains 5.2 m^2 (56 ft^2), thus having an area 2.3 times that required. This heat exchanger was a 1965 watt (6700 Btu/hr) unit fabricated with .634 cm stainless steel tubes bundled inside a 15.25 cm diameter shell. The heat exchanger was .915 meters long.

The function of the high temperature heat exchanger is to preheat the air entering the catalytic oxidizer and simultaneously cool the air entering the low temperature heat exchanger. An overall heat transfer coefficient of $4.8 \text{ Btu/hr/ft}^2/\text{°F}$ was used to calculate an area of 8.73 m^2 (95 ft^2) necessary to obtain a 367°C (660°F) temperature rise. This unit, similar to the low temperature heat exchanger, contained a .634 cm tube bundle inside a 20.3 cm diameter shell. The heat exchanger was 1.2 meters long and contained 12.1 m^2 (130 ft^2) of surface area. This 12,300 watt (42,000 Btu/hr) unit thus had an area 1.4 times the area required.

Both exchangers are fabricated from 316 stainless steel and have removable bundles to facilitate cleaning. They were purchased from Whitlock Manufacturing Company, catalogue numbers AHT 6-W-36 and AHT 8-H-48 for the small and large heat exchangers respectively.

4.2.3 Evaporator/Condenser

The function of the evaporator/condenser was to vaporize all waste liquids while simultaneously condensing moisture from the air passing through the condenser.

Evaporation occurred in two stages. The first stage utilized the latent heat transferred from the condenser to vaporize liquids sprayed against the common evaporator and condenser wall. Two atomizers (rated at 11.4 l/hr each) directed at the evaporator wall released a fine mist which was distributed along

the wall by the swirling action of the air passing through the evaporator. These fine droplets were vaporized on one side of the wall by removing 8,210 watts of heat from the airstream in the condenser. The resulting drop in temperature of the air in the condenser side of the configuration caused moisture to form on the condenser wall. An overall heat transfer coefficient of $26 \text{ Btu/hr/ft}^2/^{\circ}\text{F}$ was used to determine that 3.44 square meters of surface area was required for the heat transfer. A 96.5 cm diameter, 12 gauge stainless steel wall, 117 cm high cylindrical jacketed tank, containing 3.72 square meter of heat transfer surface area, was purchased from Stainless Products Corporation to be utilized as the evaporator/condenser. The dimpled jacket having .952 cm wide by 2.9 cm long trapezoidal passages surrounding the tank was utilized as the condenser. Treated air/vapor mixture was introduced into the jacket through an inlet manifold six passages long, and directed through the jacket by .952 cm diameter rods spaced six passages apart into an outlet manifold located at the bottom of the tank. These rods prevented the air to pass directly from the inlet to outlet manifold and force the air to contact as much heat transfer areas as possible. The tank was also surrounded by 5 centimeters of insulation to insure heat transfer only from the condenser jacket to the inside of the evaporator. The top was secured to the tank by snap clasps for ease of removal in case nozzle replacement is necessary.

Second stage evaporation was accomplished by passing dry air through the small spray chamber located within but insulated from the evaporator. The spray chamber was a 45.7 cm diameter by 73.6 cm long cylindrical polypropylene tank surrounded by a fiberglass casing. The chamber contained a 25 cm height (10 gal.) of waste liquid at a temperature of approximately 60°C (140°F). The water was circulated through a spray nozzle rated at 32.2 ℓ/hr . This second

stage of evaporation was an adiabatic process which saturated the air at 60°C (140°F) for further treatment in the subsystem.

The evaporator/condenser assembly (including the spray chamber) was rated to evaporate water at 12.3 l/hr and to condense water at 10.4 l/hr (84% efficiency) for an airflow of 94.2 Kg/hr (208 lb/hr). Figure 4-4 shows the evaporator/condenser integrated with the total subsystem.

4.2.4 Catalytic Oxidizer

The catalytic oxidizer heated incoming air and water vapor together with the gas effluents of the incinerator from 427°C (800°F) to 482°C (900°F) in the presence of a catalyst to oxidize impurities in the water vapor. The resulting purified water vapor was subsequently condensed while the non-condensable impurities were carried out of the subsystem in the airstream.

The basic configuration of the oxidizer (shown in Figure 4-5) was a cylinder 25.4 cm (10") in diameter by 38.1 cm (15") long. Hemispherical heads were bolted to the cylinder by way of mating flanges sealed with silver plated Inconel X-750 O-rings. These heads serve as transition manifolds for the air/water vapor flow to adapt between the 5 cm (2") diameter tubes and the 25.4 cm (10") cylindrical catalyst container (Figure 4-6). The oxidizer dimensions were chosen so as to reduce the velocity of the air flow through the oxidizer to obtain a 0.1 sec contact time between the water vapor and the catalyst pellets for proper catalysis.

A tradeoff was made on the diameter dimension between the pressure drop imposed and the amount of electricity needed to heat the passing air. The oxidizer diameter was chosen large enough for a minimal pressure drop and small enough to reduce the power needed to heat the catalyst bed.

This page is reproduced at the back of the report by a different reproduction method to provide better detail.

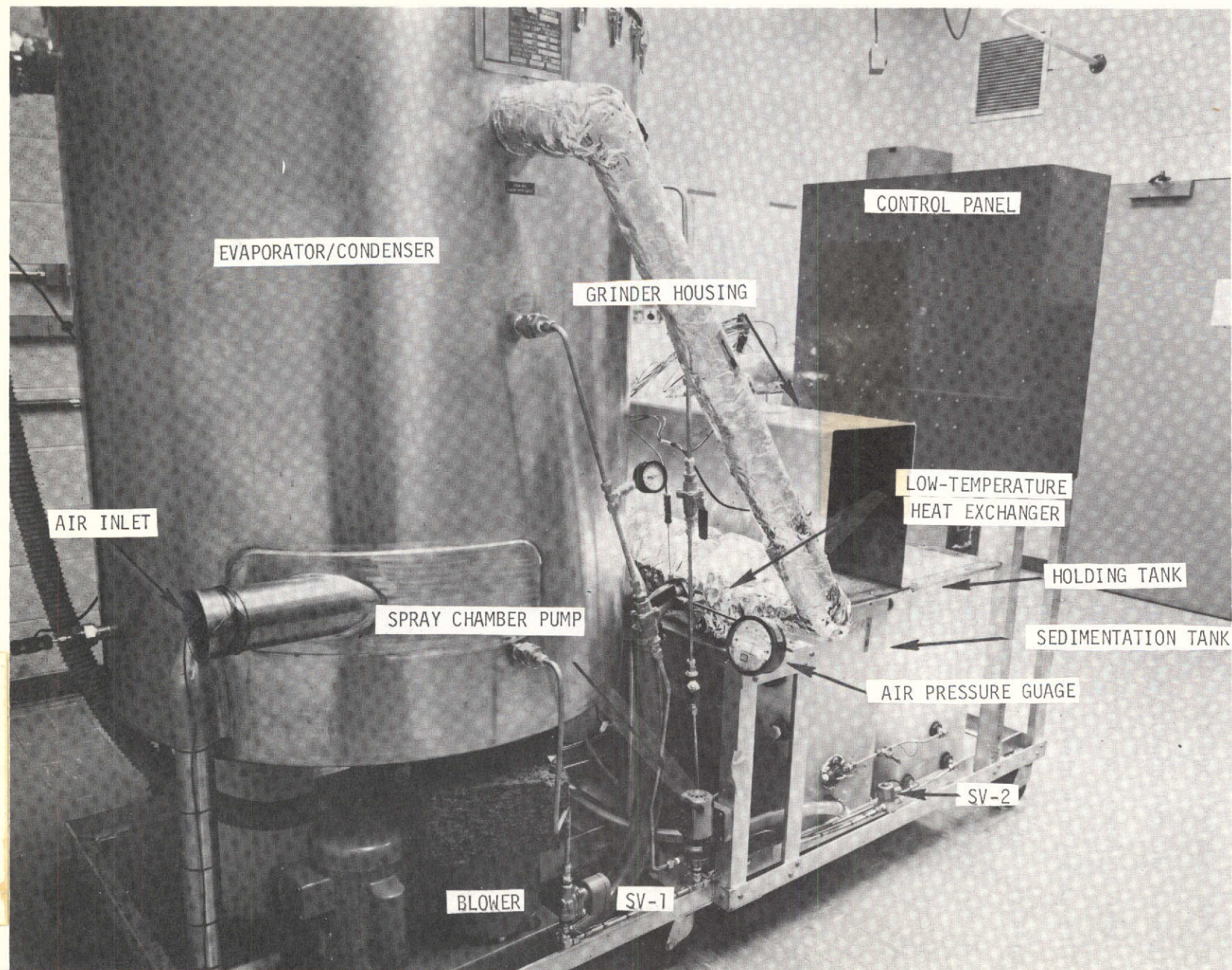


FIGURE 4-4 DOMESTIC WATER AND WASTE TREATMENT SUBSYSTEM

Heat was provided by a 5000 watt coiled tubular heater (Chromalox #TCN143853) placed inside the catalyst bed and powered by a 208V, 24 amp line. The catalyst was retained in the cylindrical portion of the oxidizer by two wire mesh screens which also aided in heat transfer to the airstream.

The catalyst employed in the oxidizer was produced by Englehard Industry. The catalyst was composed of 0.5% Ruthenium supported on .318 cm diameter x .318 cm long alumina cylinders. An enriched version of this catalyst was utilized which had an effective surface area of 200 square meters per gram.

This page is reproduced at the back of the report by a different reproduction method to provide better detail.

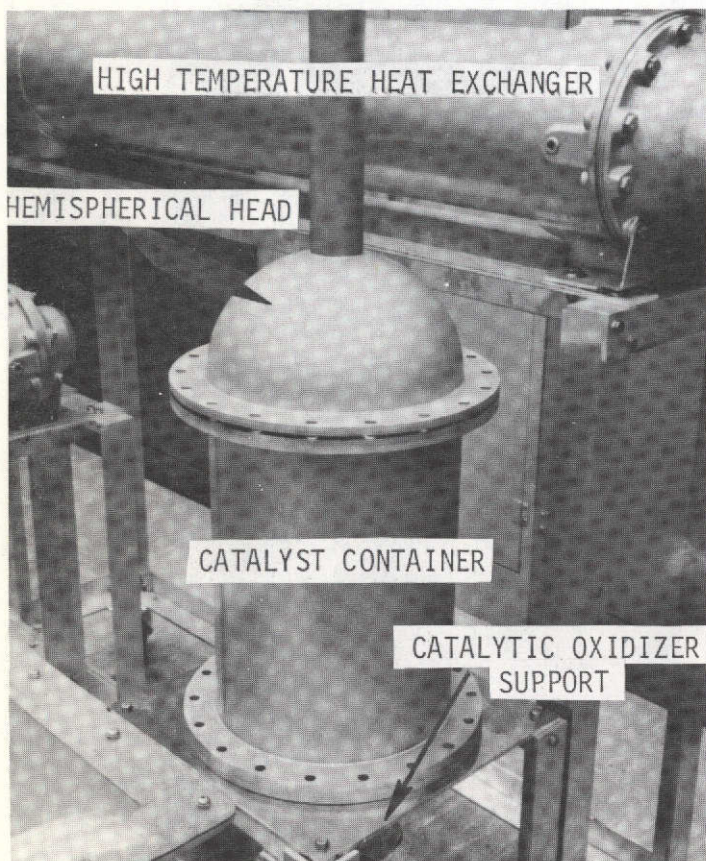


Figure 4-5. Hemispherical Head in Place on Catalyst Bed

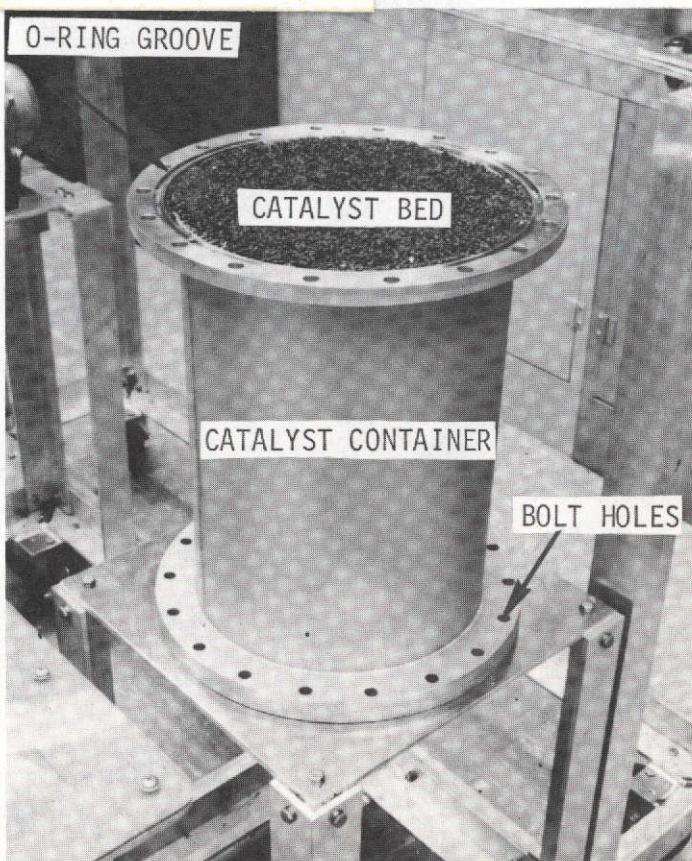


Figure 4-6. Exposed Catalyst Bed

4.2.5 Grinder

The grinder was a commercially available household waste disposal unit (General Electric #FC-250) which was adapted to an aluminum housing covering the sedimentation tank. Sewer line connection was made by inserting an 8.11 cm (3.18") diameter tube into the grinder opening and applying sealant (RTV 102 or equivalent) between the mating surfaces for an odorless seal.

All wastes were macerated by the grinder and pumped directly into the sedimentation tank for transport to the incinerator. The grinder was powered by a 115V, 5 amp, 8000 rpm motor and contained a stainless steel hopper and cutter. Figure 4-7 shows the grinder (without aluminum housing) situated on the sedimentation tank incinerator assembly.

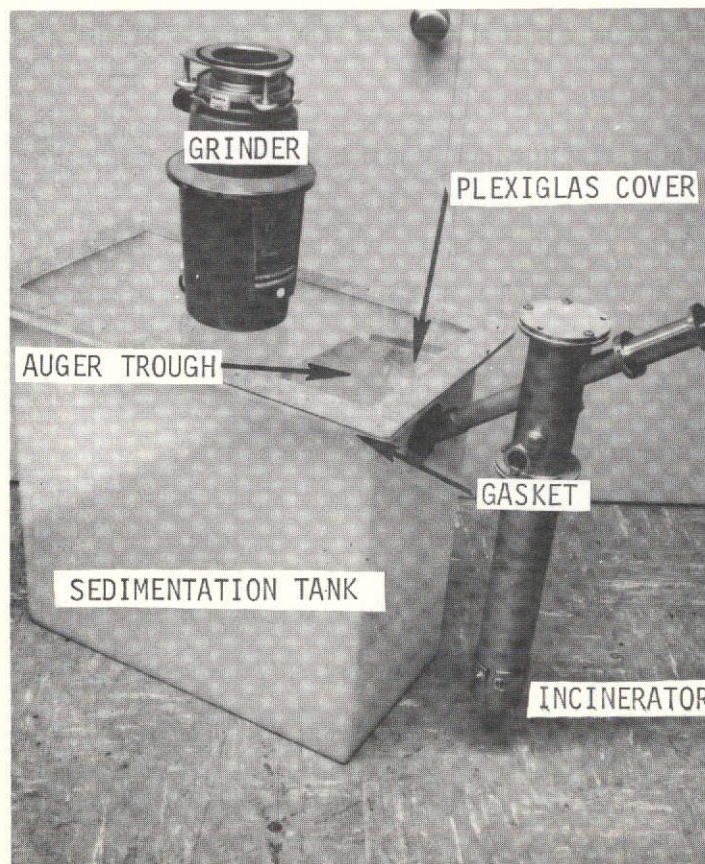


Figure 4-7. Grinder

4.2.6 Sedimentation Tank

Normally sedimentation tanks are designed to provide 90 to 150 minutes of detention based on the average rate of sewage flow. The settling tank design area was based on a surface loading rate ($\ell/\text{day}/\text{m}^2$ horizontal area) using the following criteria:

RECOMMENDED SURFACE LOADING RATES FOR VARIOUS SUSPENSIONS (Ref.1)

<u>SUSPENSION</u>	<u>LOADING RATE ($\ell/\text{day}/\text{m}^2$)</u>	
	<u>RANGE</u>	<u>PEAK</u>
Untreated Wastewater	24,445-52,965	48,891
Aluminum Flocculent	14,667-24,445	24,445
Iron Flocculent	22,000-32,594	32,594
Lime Flocculent	22,000-48,891	48,891

Following determination of the area of the tank, the detention time was determined from the following chart:

DETENTION TIMES FOR VARIOUS SURFACE LOADING RATES AND TANK DEPTHS (REF. 1)

<u>SURFACE LOADING RATE $\ell/\text{day}/\text{m}^2$</u>	<u>2.1m DEEP</u>	<u>2.4m DEEP</u>	<u>3.1m DEEP</u>	<u>3.6m DEEP</u>	<u>1.2m DEEP</u>	<u>.6m DEEP</u>
4,074	N/A	N/A	N/A	N/A	7.2	3.6
8,148	N/A	N/A	N/A	N/A	3.6	1.8
16,297	3.2	3.6	4.5	5.4	1.8	.9
24,445	2.1	2.4	3.0	3.6	1.2	.6
40,742	1.25	1.4	1.8	2.2	.7	.35

Due to the wide variation of flow rates in the sedimentation tank (0-75 ℓ/hr) with a relatively low average flow rate of 12.3 ℓ/hr , the design basis was modified somewhat. For example, using the previous table with the average flow and loading rate of 24,445 $\ell/\text{day}/\text{m}^2$, a tank area of

$$\frac{12.3 \text{ } \ell/\text{hr} \times 24 \text{ hrs/day}}{24,445 \text{ } \ell/\text{day}/\text{m}^2} = .012 \text{ m}^2 (.13\text{ft}^2)$$

of horizontal surface is required.

However, from the second table, a 24,445 $\ell/\text{day}/\text{m}^2$ loading rate with a 2.4 hr detention time requires a tank depth of 2.4m.(8 ft.). To reduce the tank depth to a feasible 0.6m.(2 ft.) and a detention time of 1.8 hrs, then a surface loading of only 8,148 $\ell/\text{day}/\text{m}^2$ is allowed.

The allowable flow rate for a .18m (2 ft²) surface area is

$$.18\text{m}^2 \times 8,148 \text{ } \ell/\text{day}/\text{m}^2 \times \frac{1\text{day}}{24 \text{ hrs}} = 62.8 \text{ } \ell/\text{hr}.$$

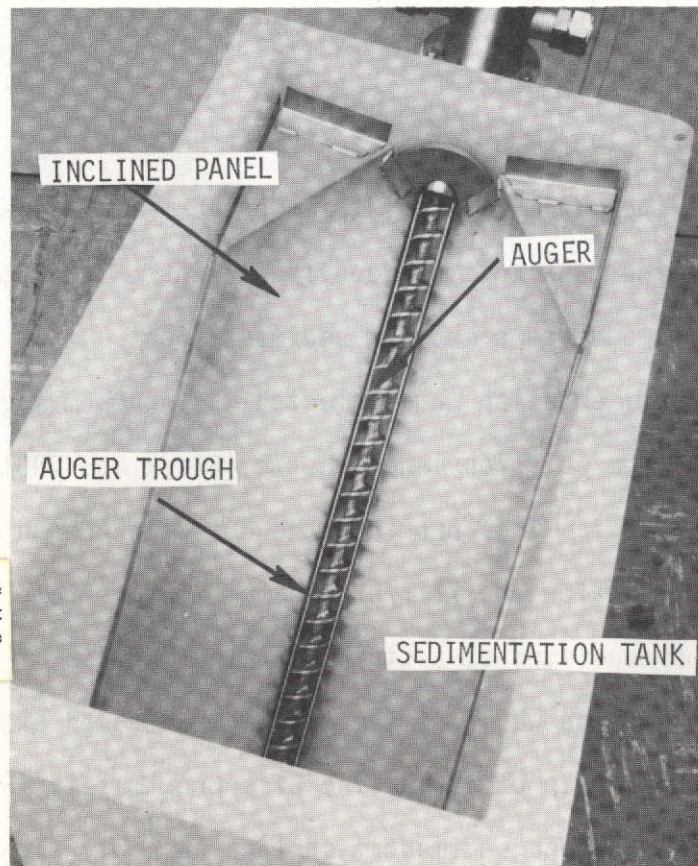
This approaches the maximum flow rate expected (75 ℓ/hr) and should permit some modification of the tank internal configuration to facilitate the auger operation with minimum adverse effect on sedimentation.

Therefore, the sedimentation tank selected was an 0.6m x .3 m x .6m high container fabricated from polypropylene plastic (Stock No. 09016 supplied by U.S. Plastics Corporation). This provided the 2 ft tank depth desired and the 2 ft² surface area needed for the 75 ℓ/hr maximum loading rate.

Auger provisions consisted of a stainless steel trough, fabricated to match the auger and affixed to the walls of the tank. The trough extended from the bottom of the tank to the top of an incline of approximately 45°. Figure 4-8 depicts the auger, trough, and sedimentation tank assembly with the incinerator partially shown in the background.

Movement of the required 2.72 Kg/day (6 lbs/day) of solids waste into the incinerator was accomplished by a motor driven auger. This item had a 2.54 cm outside diameter with a "flight" pitch of approximately 2.54 cm on a .95 cm spindle. It provided a volume per "flight" of 4.09 cm³. The average volumetric input of solids waste was approximately 3.3 cm³/min. Assuming 10% of the auger

volume was effective in moving the solids, the required speed of the auger was approximately 10 rpm. The auger was partially enclosed in a tubular trough running above waterlevel to the point at which the solids were deposited into the incinerator. Then, the auger spindle passed through an O-ring seal and a set of bearings to the drive motor coupling. The lower end of the auger was supported by a stainless steel bushing.



This page is reproduced at the back of the report by a different reproduction method to provide better detail.

Figure 4-8. Sedimentation Tank

To obtain low speed with reasonably high output torque, a catalog #507 gearmotor manufactured by Bodine Electric Company was selected. The motor was

rated at 8.28 watts and delivered .288 m-Kg (25 lb-in) torque at 9.4 rpm. The motor operated on 115V, 60 Hz, 1 phase power.

The two filters installed into the sedimentation tank were readily cleaned by simply turning the spindle. These operated in parallel and had a 0.2 millimeter spacing.

4.2.7 Holding Tank

The rate at which sewage was added to the subsystem was dependent upon the user and must be accommodated by the system. Accumulations of up to 83.4 liters (22 gallons) of water in the system was anticipated (Ref. 2) based upon the hydrograph of the daily water usage profile for a 4-person household (Figure 4-9). Since this hydrograph represents an arbitrary water usage pattern, the holding tank was sized to contain 113.8 liters (30 gallons) of water. The holding tank selected was the same as that being utilized as the sedimentation tank (Stock No. 09016, United States Plastic Corporation).

Provisions were made in the holding tank to accept the overflow from the sedimentation tank and to discharge water into the subsystem pumps. A drain was also installed near the bottom of the tank. Level sensors were placed inside the tank to control pump on/off operation and to provide an alarm for overflow.

4.2.8 Incinerator

Household effluent entering the subsystem contained an average of 2.72 Kg (6 pounds) of dry solids per day. This material was collected in the sedimentation tank and transported to the incinerator by the auger assembly where it was reduced to ash. Heat for the incineration process was provided by electric heating elements arranged around the outside of the incinerator chamber. Ashes resulting from the incineration process was stored in the incineration chamber and removed periodically by disassembly of the incinerator.

65 GPD INPUT; 3.25 GPH EVAPORATION RATE (FOR 20 HOURS)

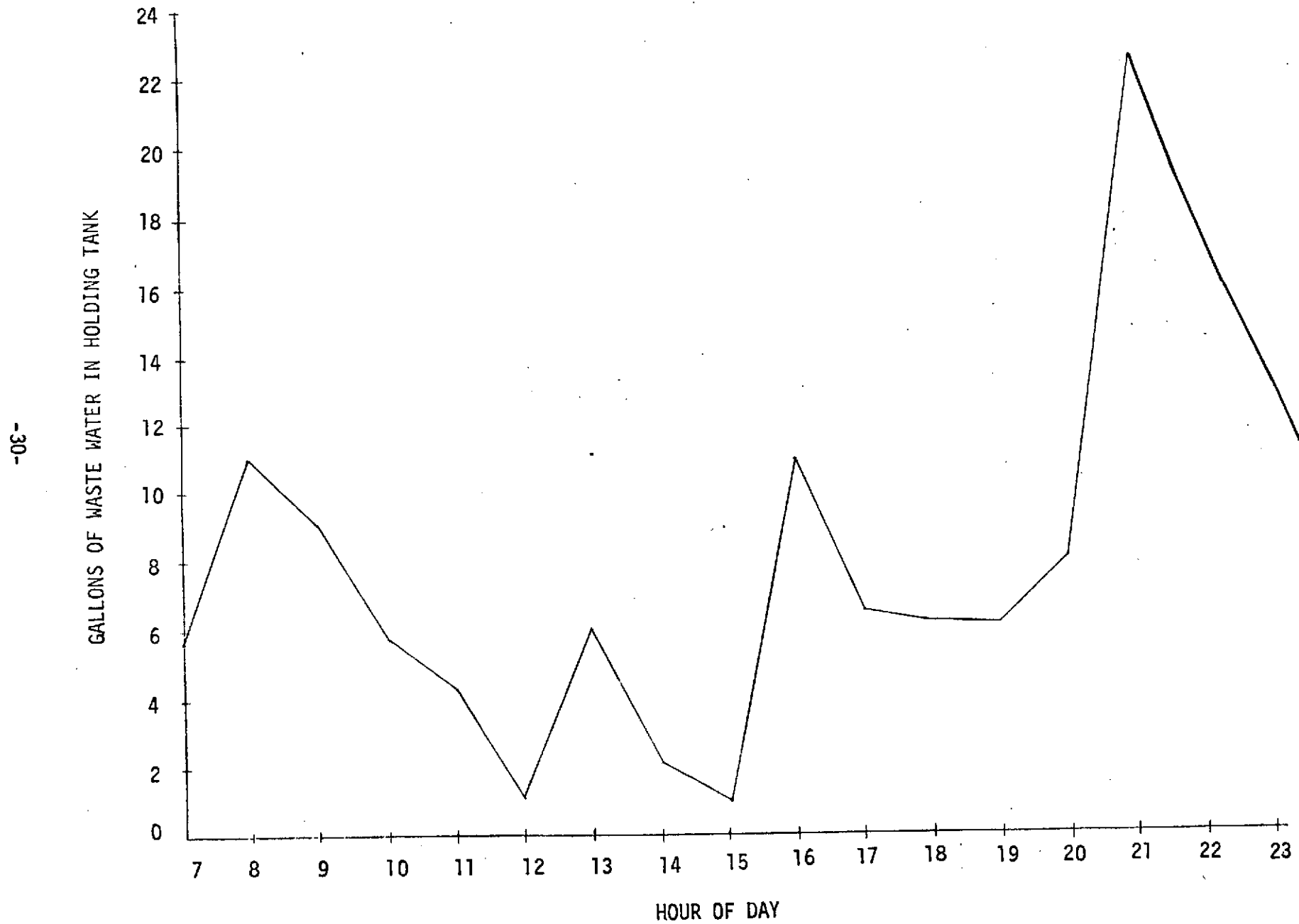


FIGURE 4-9 WATER USAGE PROFILE

The incinerator size was determined by the volume of the material to be burned.

Using 2.72 Kg (6 pounds) per day as the average solids input rate and assuming a specific gravity of 1 for the solid waste, the volume rate of trash input was:

$$\frac{2.72 \text{ Kg}}{1010 \frac{\text{Kg}}{\text{m}^3}} \times \frac{1,000,000}{24 \times 60} = 1.90 \text{ cm}^3/\text{min} (0.115 \text{ in}^3/\text{min.})$$

Assuming 90% volume reduction due to incineration and storage duration of 7 days the incinerator volume required for ash storage was:

$$\frac{2.72 \text{ Kg}}{1010} \times \frac{1,000,000}{24 \times 60} \times 7 \times 0.1 = 1900 \text{ cm}^3/\text{min} (116 \text{ in}^3)$$

Thermal energy required for the incineration process was as follows:

- 1) Heat to incinerate solids (assuming specific heat of 1 BTU/lb/°F):

$$Q_s = \frac{6 \times 1 \times 850}{24} = 212.50 \text{ BTU/HR.}$$

- 2) Heat to evaporate moisture contained in solids, assuming 2 lbs of water per pound of solids:

$$Q_c = \frac{12 \times 1 \times 1400}{24} = 700 \text{ BTU/HR.}$$

- 3) Heat to warm air supply to incineration chamber at 1 cfm.

$$Q_a = 1 \times 0.083 \times .24 \times 60 \times 850 = 1025 \text{ BTU/HR.}$$

Total heat required thus is approximately 620 watts, allowing for 10% loss from housing to ambient and ignoring calorific value of material being incinerated.

Assuming the cylinder temperature to be 482°C (900°F), the allowable total wattage for a 3.8 cm (1-1/2") wide heater is 300 watts. The cylinder length was approximately 40.6 cm (16 inches), therefore 3 heating elements, each of 200 watts capacity, can be conveniently used. These heating bands were 7.6 cm (3 inches) in diameter and were powered by an 115V, 60 cycle power.

The heated incineration chamber could be removed for cleaning by extracting the 6 bolts from the mating flanges and removing the ash.

Incinerator integration with the sedimentation tank is shown in Figure 4-10 (auger motor not shown).

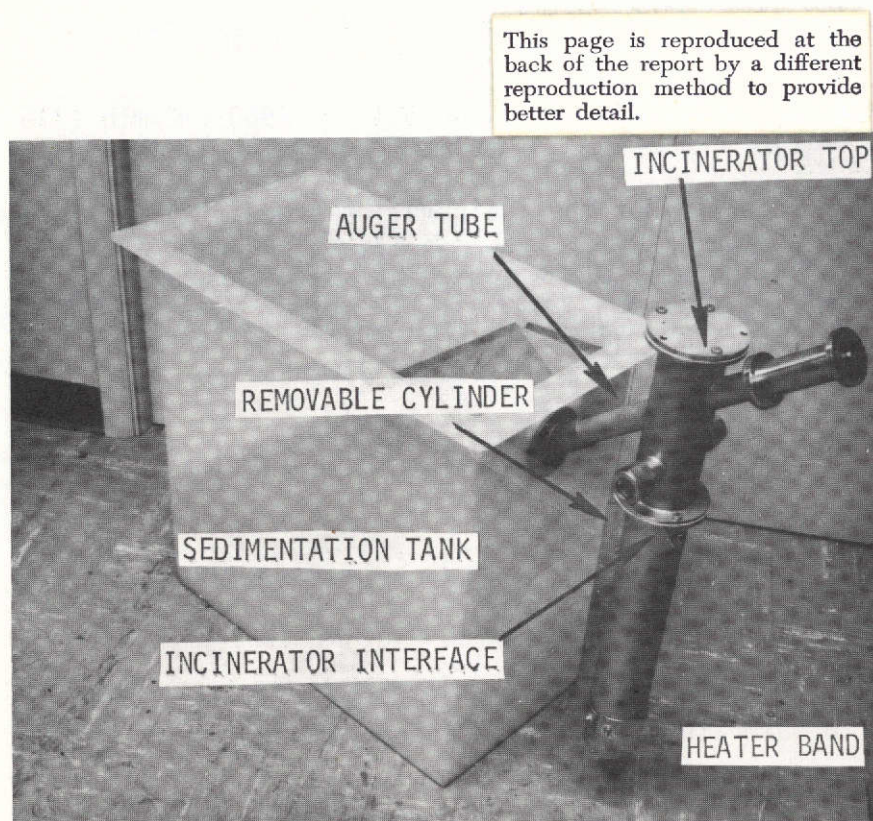


Figure 4-10. Incinerator

4.2.9 Pumps

This subsystem utilized two centrifugal pumps for transporting liquids from the holding tank into the evaporator and spray chamber. Pump #1 (which transported

liquids into the evaporator) is manufactured by Micropump Inc. and operated on a 115V, 50 cycle, 1 phase power. This pump was a high flow continuous duty pump model #10-84-316 delivering 22.7 l/hr (6 ga/hr) at 1.05 ksc (15 psi). Pump #2, which recirculated liquid in the spray chamber at 30.3 l/hr (8.5 gal/hr) operating at 1.75 ksc (25 psi), was manufactured by Eastern Industries, Model No. DH-11.

Both pumps are fabricated from cres. 316 stainless steel.

4.2.10 Recovered Water Tank

A water recovery tank was provided for the purpose of effluent water sampling. The tank was positioned below the condenser level in order to allow gravity to feed the condensate into the tank. A condensate overflow and an air vent were provided on the tank.

The tank selected was a 20.8 liter (22 quart) Polyethene tank available from U. S. Plastics Corporation, Model No. 68055.

4.3 Subsystem Controls

The control system was designed with the objective of integrating and regulating the individual activities of each component such that the total process could operate without continual attention. The functions requiring a regulating control were the catalytic oxidizer and incinerator temperatures, the water level in the holding tank, and the water level in the spray chamber. On-off controls were provided for the blower, pump, auger and grinder although these may be regulated by other component functions. The wiring schematic for the control panel is shown in Figure 4-11. The control sensor locations were shown in Figure 4-12 and descriptions are given in the following paragraphs.

4.3.1 Catalytic Oxidizer

Electrical power to the heating units was regulated by a meter relay pyrometer. Thermocouples in the catalytic oxidizer bed sense the temperature

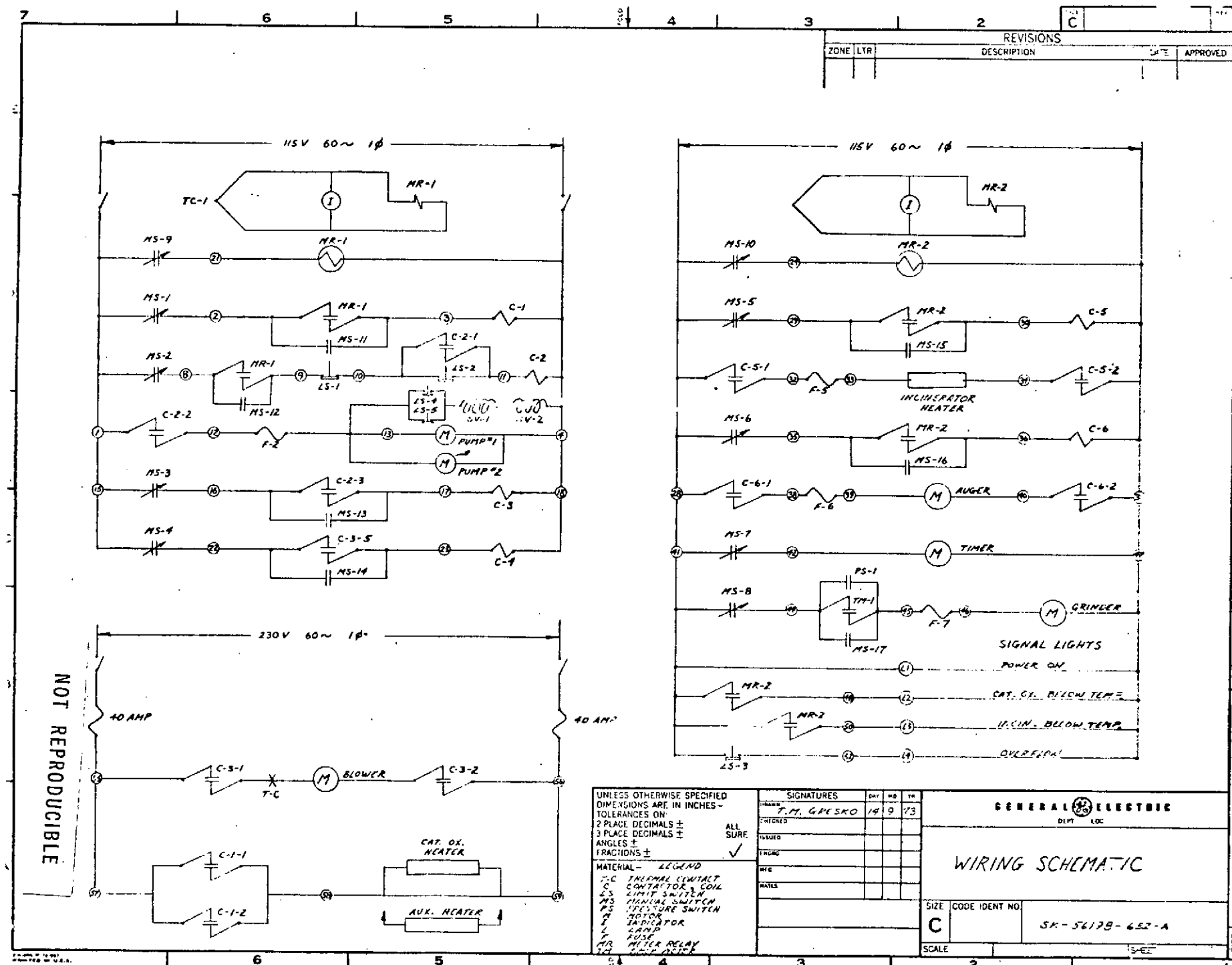


FIGURE 4-11 WIRING SCHEMATIC

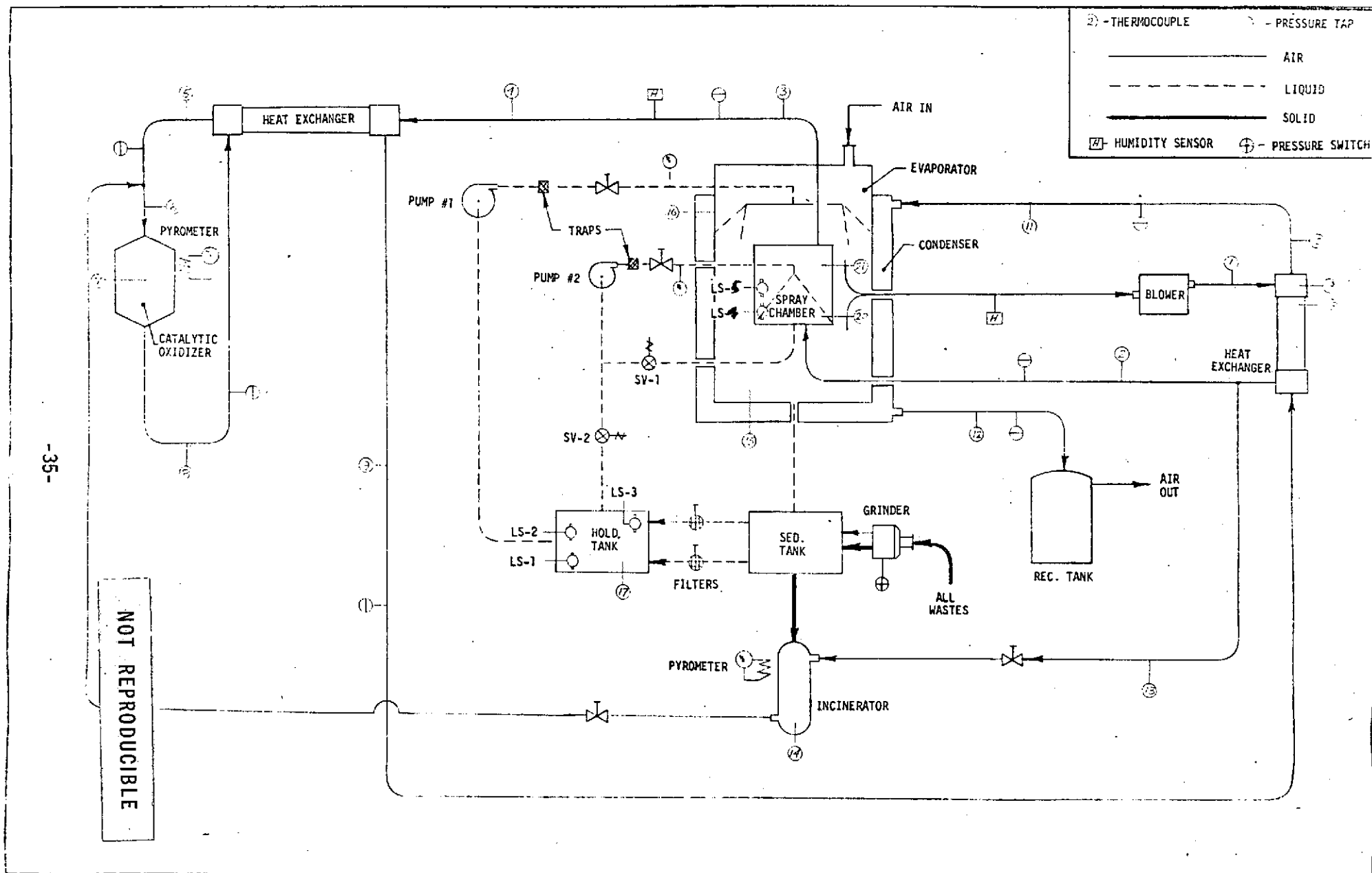


FIGURE 4-12 INSTRUMENTATION LOCATIONS

giving both a temperature indication, and through the meter relay, an on-off control. Contacts MR-1 in the meter relay operated a power contractor C-1 which directly controlled electrical power to the heater. The meter HIGH TEMP set point was 371°C (700°F) with a range of $\pm 50^\circ$ at the sensing location. The meter relay also had a set of "Low Temperature Alarm" contacts MR-2 which were open when temperatures were below the operating range, and used in this application to inhibit full operation of the subsystem whenever temperatures in the catalytic oxidizer were too low for proper operation.

4.3.2 Incinerator

Electrical Power to the incinerator heater was regulated in the same way as the oxidizer with the high set point temperature at 482°C (900°C) and the low temperature alarm contacts used to inhibit operation of the solids auger.

4.3.3 Holding Tank Liquid Level

Holding tank liquid levels were regulated by suspending forced evaporation whenever the level was low. Two float switches were located in the tank. LS-1 opened when the level became low and through contactors C-2, C-3 and C-4 opened the power circuits of the liquid pumps and blower. As replenishing liquid came into the tank, LS-1 closed but activity of the pump and blowers was not inhibited until the high level switch LS-2 closed. The difference in liquid levels for LS-1 and LS-2 represented approximately 19 gallons, a value chosen to allow reasonable storage capacity above the high level turn-on and still avoid repeated transient start-up conditions during which operation may deviate from optimum conditions. Any level above LS-2 tripped LS-3 and turned on the overflow alarm light located on the control panel. All component operations were ceased until the condition was corrected by removing some water from the holding tank until reaching a safe level.

4.3.4 Auger

Power to drive the auger electric motor was applied continuously until incinerator temperatures dropped below normal. Contact MR-2 in the meter relay incinerator pyrometer unit opened whenever temperatures sensed were below the low level alarm setting.

4.3.5 Grinder

Control of the grinder was contained in a timer circuit. TM-1 contacts driven from a timer motor operated the grinder for a period of 5 minutes every 1/2 hour. However, when wastes were received at a relatively high rate, any significant back-up was sensed by a pressure switch. At an over pressure of 30.4 cm (12") H₂O or more, PS-1 closed to start the grinder operation if it was not already operating because of the normal timing sequence. This pressure switch will be installed in the sewer inlet pipe after household integration.

4.3.6 Spray Chamber

Water level in the spray chamber was maintained similar to that of the holding tank. With the chamber empty, LS-4 opened SV-2 and closed SV-1 allowing pump #2 to fill the spray chamber with liquid from the holding tank. When LS-5 was tripped (sump formed), SV-1 was opened and SV-2 closed, causing the pump to operate in a closed loop.

4.3.7 Other Control Features

Additional control aspects were incorporated including overload, separate manual control and indicating features. Each of the larger power consuming units (Motors - Heaters) was provided with separate fusing for overload protection. In addition the whole power circuit was protected at the main disconnect with fuses.

Each function had provision for separate isolation/operation through manually operated switches. During test operations individual components could be selectively locked out by opening manual switches MS-1 to MS-8 or individually operated by closing MS-11 to 17.

Indicators were provided for two temperatures and three alarm condition. Pyrometer indicators gave temperature readings of both the catalytic oxidizer and the incinerator. Indicator lights signaled the presence of electric power, low operating temperature of the catalytic oxidizer or the incinerator, and a holding tank overflow condition.

4.4 Instrumentation

Iron-Constant thermocouples were provided together with two humidity sensors to readout conditions at various points throughout the subsystem (See Figure 4-12 for locations).

One air pressure gauge was provided with the subsystem and located between the blower and low temperature heat exchanger. Although this location is the highest pressure and is therefore of most concern, other ports were provided throughout the subsystem to measure pressure where desired.

Two humidity sensors were delivered with the system; one located between the evaporator and the blower to measure evaporation rates and the second located between the spray chamber and the high temperature heat exchanger to measure the water absorption rate.

Water pressure from the pumps was measured by a pressure gauge in-line with each pump. These gauges aided in observing proper pump operation and enabled a visual check of any nozzle clogging.

4.5 Subsystem Interfaces

Table 4-1 summarizes the installation interfaces required for the demonstration model. Figure 4-13 shows the integration of the subsystem to a sewage line with an overflow from the unit to drain excess liquid when incoming flow exceeds the 246 liters/day (65 gal/day) capacity. The sub-level installation permits a gravity feed of sewage and an overflow drainage.

Addition of an air vent line exhausting the hot, humid air from the condenser to an external outlet is required. This reduces air conditioning load and, in case of an oxidizer malfunction, minimizes the possibility of odors ejected into living areas or working areas.

Electrical power requirements were based on the equipment values shown in Table 4-2. These requirements were expected to be substantially reduced for a production prototype model.

Floor loading listed in Table 4-1 is calculated from the individual component weights shown in Table 4-3. The subsystem was supported by a modularized aluminum frame (with wheels) which could be separated for movement through small passageways.

TABLE 4-1. INSTALLATION INTERFACES

1.0 ELECTRICAL

- a) Standard 115/230 volt line, 60 Hz, 1 phase.
- b) Standard 230 volt line, 60 Hz, 1 phase, - 40 amp circuit breaker.
- c) Standard 230 volt line, 60 Hz, 1 Phase, - 25 amp circuit breaker.
- d) 14 Kw peak load.

2.0 SEWAGE

- a) Inlet connection .476 cm (3/16 inch) diameter tube inserted in the grinder and sealed.
- b) Overflow connection - 1.9 cm (3/4 inch) female pipe fitting.

3.0 RECOVERED WATER

- a) Overflow to the recovery tank - 1.9 cm (3/4 inch) female pipe fitting.

4.0 GAS VENT

- a) Standard 5.07 cm (2 inch) tube vent line.

5.0 MECHANICAL

- a) Floor loading is 513 Kg (1130 lbs) based on dry weights in weights in Table 4-3. An additional 136 Kg (300 lbs) is estimated for process liquids.
- b) Envelope 173 cm x 242 cm x 202 cm (68" x 96" x 80") high plus .9 meters (3 ft) clearance on all sides for operation maintenance.

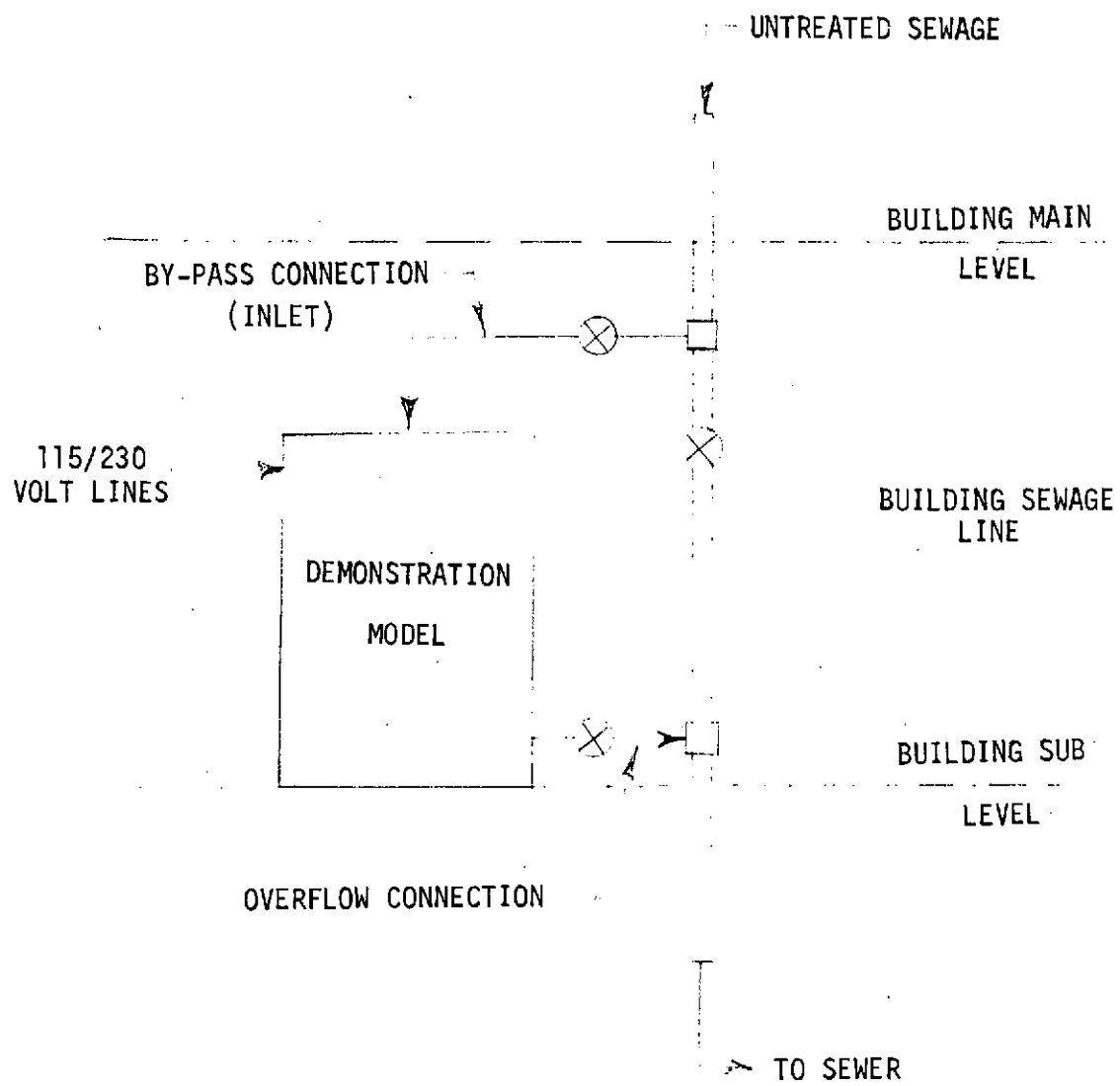


FIGURE 4-13 SUBSYSTEM INTERFACES

TABLE 4-2 ELECTRICAL POWER REQUIREMENTS

<u>COMPONENT</u>	<u>VOLT</u>	<u>AMPS</u>	<u>WATTS</u>
* BLOWER	230	12	2760
INCINERATOR	115	5	600 (40 AVE)
CATALYTIC OXIDIZER HEATER	230	22	5000 (420 AVE)
GRINDER	115	5	575 (38 AVE)
*PUMP #1	115	0.6	75
*PUMP #2	115	0.8	94
**HOT WATER HEATER	230	22	5000 (420 AVE)
*AUGER	115	0.1	10
*CONTROLS	115	----	-----

* CONTINUOUS DUTY COMPONENTS

** HOT WATER HEATER ADDITION IS EXPLAINED LATER

PEAK WATTAGE = 14,114

AVERAGE WATTAGE = 3,857

TABLE 4-3. SUBSYSTEM WEIGHT

Evaporator/Condenser	(350 lbs)	159 Kg
High Temperature Heat Exchanger	(212 lbs)	96 Kg
Low Temperature Heat Exchanger	(97 lbs)	44 Kg
Grinder	(15 lbs)	6.8 Kg
Pump #1	(4 lbs)	1.8 Kg
Pump #2	(2 lbs)	.9 Kg
Blower	(50 lbs)	22.6 Kg
Recovered Water Tank	(10 lbs)	4.5 Kg
Sedimentation Tank	(20 lbs)	9.1 Kg
Holding Tank	(20 lbs)	9.1 Kg
Auger/Motor	(10 lbs)	4.5 Kg
Incinerator	(15 lbs)	6.8 Kg
Catalytic Oxidizer	(75 lbs)	34 Kg
Plumbing	(70 lbs)	32.8 Kg
Control Panel	(50 lbs)	22.6 Kg
Structure	(100 lbs)	45 Kg
Hot Water Heater	(30 lbs)	13.6 Kg
Liquid		
	<hr/> (1130 lbs)	<hr/> 513 Kg

5.0 SUBSYSTEM TESTS, RESULTS AND DISCUSSION

Two major tests were performed on the subsystem. Descriptions and results are given below.

5.1 Functional Test

The functional test was performed on the subsystem to verify its integrity and to determine proper operation of all components, subassemblies and test instrumentation.

This test lasted four days and was a prelude to the three day performance test. System air flow, pump flows, incinerator and catalytic oxidizer temperatures were established and general operating experience was obtained.

Nozzle clogging was a continual problem during the test causing long down time to clean the nozzles. Screen traps were then added in line between the pumps and the nozzles facilitating access for cleaning and affording minimum down time when clogged.

A second cleanable filter was also added due to the accumulation of water in the sedimentation tank which was unable to flow into the holding tank as rapidly as it was being removed by the pumps. This addition corrected the problem by supplying more flow area between the tanks.

Band heaters mounted on the periphery of the catalytic oxidizer proved ineffective in maintaining the catalyst bed at 482°C (900°F). Propane was then added to the airstream before entering the catalyst bed so as to bring it to its proper operating temperature. This being only a temporary solution,

a tubular coil heater was placed directly in the catalyst bed for the performance test in order to eliminate the propane addition and reduce heat losses inherent in the band heaters.

The prepared water solution injected into the system included the following:

18.9 Liters of water

52 Grams of dishwasher detergent (Fisher Scientific) Biodegradable "Sparkleen"

48 Grams of creme deodorant soap (Sugar Beet Product Company)

11 Grams of Sugar

46 Grams of Used Coffee Grinds

680 Grams of Dog Food

The water recovered was clear with no noticeable odors, however, no water analysis was performed. The ash removed from the incinerator was dry and weighed 0.4 grams, indicating an approximate 99% solids reduction.

After all equipment operation verification was made, the two cleanable traps were added in line with the spray nozzles, the extra cleanable filter addition was made between the sedimentation and the holding tanks, and the coiled tubular heater was placed inside the catalyst bed.

After verifying operation of these additional components, preparations for the three day performance test were made.

5.2 Performance Test

During the performance test, the subsystem processed the wastes listed in Table 5-1. Subsystem schematic for the performance test is shown in Figure 5-1.

The purpose of this test was threefold:

- 1) To obtain general operating experience under actual use input conditions.
- 2) To acquire data which provided optimization and maintenance information.
- 3) To obtain subsystem process rates as a check on component performance.

The subsystem temperatures from the three day performance test are shown in Table 5-2 and are correlated with the schematic shown in Figure 5-2.

Both the actual evaporation rate shown in Figure 5-3 and the actual condensation rate shown in Figure 5-4 are low. This was due to the relatively low output temperature of the spray chamber 53.1°C (125°F) since it contains approximately 20% less water vapor at this temperature than it does at 60°C (140°F) saturated (design temperature), therefore preventing latent heat transfer through the condenser wall.

Two alternatives were available to obtain proper output temperature and therefore proper process rates:

- 1) Raise temperature of the inlet air to the spray chamber.
- 2) Raise the temperature of the circulating water in the spray chamber.

WASTE WATER MODEL

	<u>ℓ/DAY</u>	<u>GALLONS/DAY</u>
1. Urine	11.4	3
2. Toilet Flush	Recycle	Recycle
3. Bathing	72	19
4. Laundry	Recycle	Recycle
5. Dishwater	56.7	15
6. Drinking/Cooling	45.4	12
7. Utility Sink	30.3	8
8. Lavatory	30.3	8
	<hr/>	<hr/>
	246.1	65

WASTE SOLIDS MODEL (NONMETALLIC)

	<u>Kg/DAY</u>	<u>LB/DAY</u>
1. Fecal Material	.45	1.0
2. Excess Food	.45	1.0
3. Food Wrappers	.45	1.0
4. Tissue Wipes	.23	0.5
5. Grease	.23	0.5
6. Facial and Cranial Hair	.14	0.3
7. Miscellaneous	.77	1.7
	<hr/>	<hr/>
	2.72	6.0

TABLE 5-1 WASTE INPUTS



FIGURE 5-1 SUBSYSTEM CONFIGURATION

P E R F O R M A N C E T E S T D A T A

<u>T/C#</u>	<u>LOW TEMPERATURE</u>	<u>HIGH TEMPERATURE</u>
1	75°C (165°F)	80°C (175°F)
2	132 (270)	143 (290)
3	53 (125)	54 (130)
4	53 (125)	54 (130)
5	343 (650)	366 (690)
6	327 (620)	354 (670)
7	538 (1000)	538 (1000)
8	466 (870)	538 (1000)
9	104 (220)	113 (235)
10	74 (175)	82 (180)
11	74 (175)	82 (180)
12	40 (105)	43 (110)
13	35 (95)	53 (125)
14	427 (800)	427 (800)
15	40 (105)	43 (110)
16	40 (105)	43 (110)
17	32 (90)	38 (100)
R.H. #1	90 (90)	100 (100)
R.H. #2	90 (90)	100 (100)
AIR FLOW	850 l/m (30)	894 l/m 31.5 CFM)
ROOM TEMP	21°C (75°F)	21°C (75°F)
ROOM R.H.	50 (50)	55 (55)

TABLE 5-2 PERFORMANCE TEST DATA

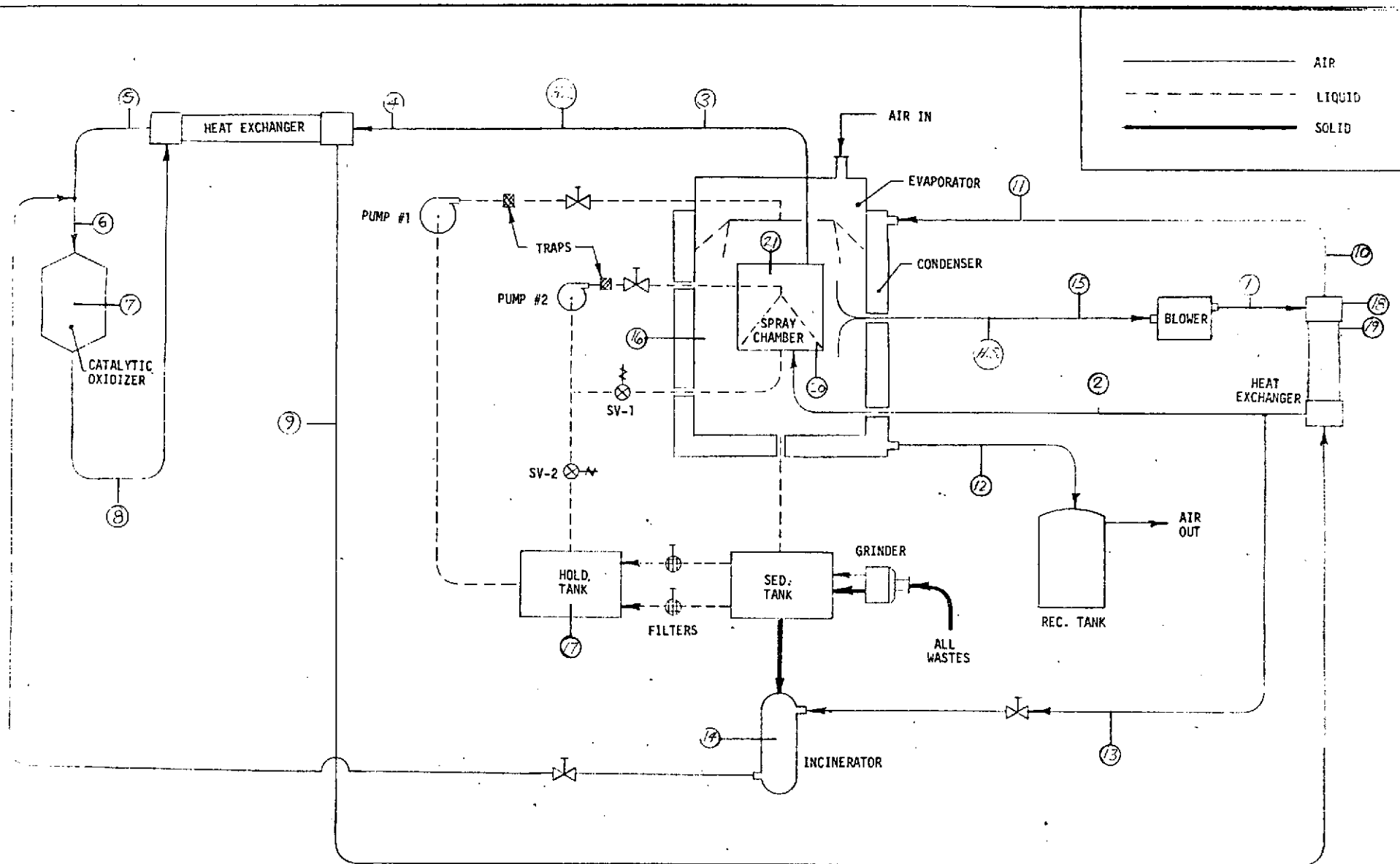


FIGURE 5-2 THERMOCOUPLE LOCATIONS

EVAPORATION RATE

1. THEORETICAL

OUTLET OF SPRAY CHAMBER = .1116 Kg H₂O/Kg AIR

INLET TO EVAPORATOR = .0085 Kg H₂O/Kg AIR

.1031 Kg H₂O/Kg AIR

$$894 \text{ } \ell/\text{min} \times 1.08 \times 10^{-3} \frac{\text{Kg}}{\ell} \text{ AIR} \times 60 \frac{\text{MIN}}{\text{HR}} = 58.1 \text{ Kg/HR (125.5 LB/HR)}$$

$$.1031 \frac{\text{Kg}}{\text{Kg}} \text{ H}_2\text{O} \times 58.1 \text{ Kg/HR} = 6.0 \frac{\text{Kg}}{\text{HR}} \text{ H}_2\text{O} \quad (13 \frac{\text{LB}}{\text{HR}} \text{ H}_2\text{O})$$

$$\text{RATE } 6.0 \frac{\text{Kg}}{\text{HR}} \text{ H}_2\text{O} \times 24 \frac{\text{HR}}{\text{DAY}} \times \frac{1 \ell}{\text{Kg}} = 144 \text{ } \ell/\text{DAY} \quad (37.5 \text{ GAL/DAY})$$

2. ACTUAL

$$4.26 \text{ } \ell/\text{HR} \times 24 \frac{\text{HR}}{\text{DAY}} = 102.5 \text{ } \ell/\text{DAY} \quad (27 \text{ GAL/DAY})$$

3. REQUIRED

$$246 \text{ } \ell/\text{DAY} \quad (65 \text{ GAL/DAY})$$

FIGURE 5-3 EVAPORATION RATE

C O N D E N S A T I O N R A T E

1. THEORETICAL

OUTLET OF SPRAY CHAMBER = .1116 Kg H₂O/Kg AIR

OUTLET OF CONDENSER = .0600 Kg H₂O/Kg Air

.0516 Kg H₂O/Kg AIR

$$894 \text{ } \ell/\text{MIN} \times 1.08 \times 10^{-3} \frac{\text{Kg AIR}}{\ell} \times 60 \frac{\text{MIN}}{\text{HR}} = 58.1 \text{ Kg/HR (125.5 LB/HR)}$$

$$.0516 \text{ Kg H}_2\text{O/Kg AIR} \times 58.1 \text{ Kg/HR} = 3.0 \text{ Kg/HR H}_2\text{O (6.5 LB/HR H}_2\text{O)}$$

$$\text{RATE} = 3.0 \frac{\text{Kg}}{\text{HR}} \text{ H}_2\text{O} \times 24 \frac{\text{HR}}{\text{DAY}} \times \frac{1 \ell}{\text{Kg}} = 72 \ell/\text{HR (18.7 GAL/DAY)}$$

2. ACTUAL

$$.214 \ell/\text{HR} \times 24 \frac{\text{HR}}{\text{DAY}} = 5.15 \ell/\text{DAY (1.35 GAL/DAY)}$$

3. GOAL

$$80\% \times 246 \ell/\text{DAY} = 197 \ell/\text{DAY (52 GAL/DAY)}$$

FIGURE 5-4 CONDENSATION RATE

The latter was chosen because of the physical difficulty of the former, although both would accomplish the same goal, i.e., higher outlet temperature with 100% R.H.

Heat was applied to the water by the addition of a heater placed directly in line between the pump and the spray chamber (See Figure 5-5). System temperatures are shown in Table 5-3 and are correlated with T/C numbers in Figure 5-5.

The evaporation and condensation results are shown in Figures 5-6 and 5-7 respectively. Process (evaporation) requirements were exceeded although condensation goals were not attained.

TEST DATA AFTER ADDITION OF HOT WATER HEATER

<u>T/C#</u>	<u>LOW TEMPERATURE</u>	<u>HIGH TEMPERATURE</u>
1	77°C (170°F)	79°C (175°F)
2	95 (205)	99 (210)
3	58 (137)	60 (140)
4	56 (135)	60 (140)
5	388 (730)	390 (735)
6	371 (700)	380 (715)
7	538 (1000)	538 (1000)
8	527 (980)	532 (990)
9	121 (250)	127 (260)
10	82 (180)	82 (180)
11	79 (175)	82 (180)
12	49 (120)	52 (125)
13	32 (90)	43 (110)
14	427 (800)	427 (800)
15	46 (115)	46 (115)
16	41 (105)	43 (110)
17	27 (80)	32 (90)
18	93 (200)	99 (210)
R.H.#1	100 (100)	100 (100)
R.H.#2	100 (100)	100 (100)
AIR FLOW	1360 ℓ /m (48CFM)	1470 ℓ /m (52CFM)
ROOM TEMP	21 (70°F)	24 (75°F)
ROOM RH	50 (50)	55 (55)

TABLE 5-3 TEST DATA

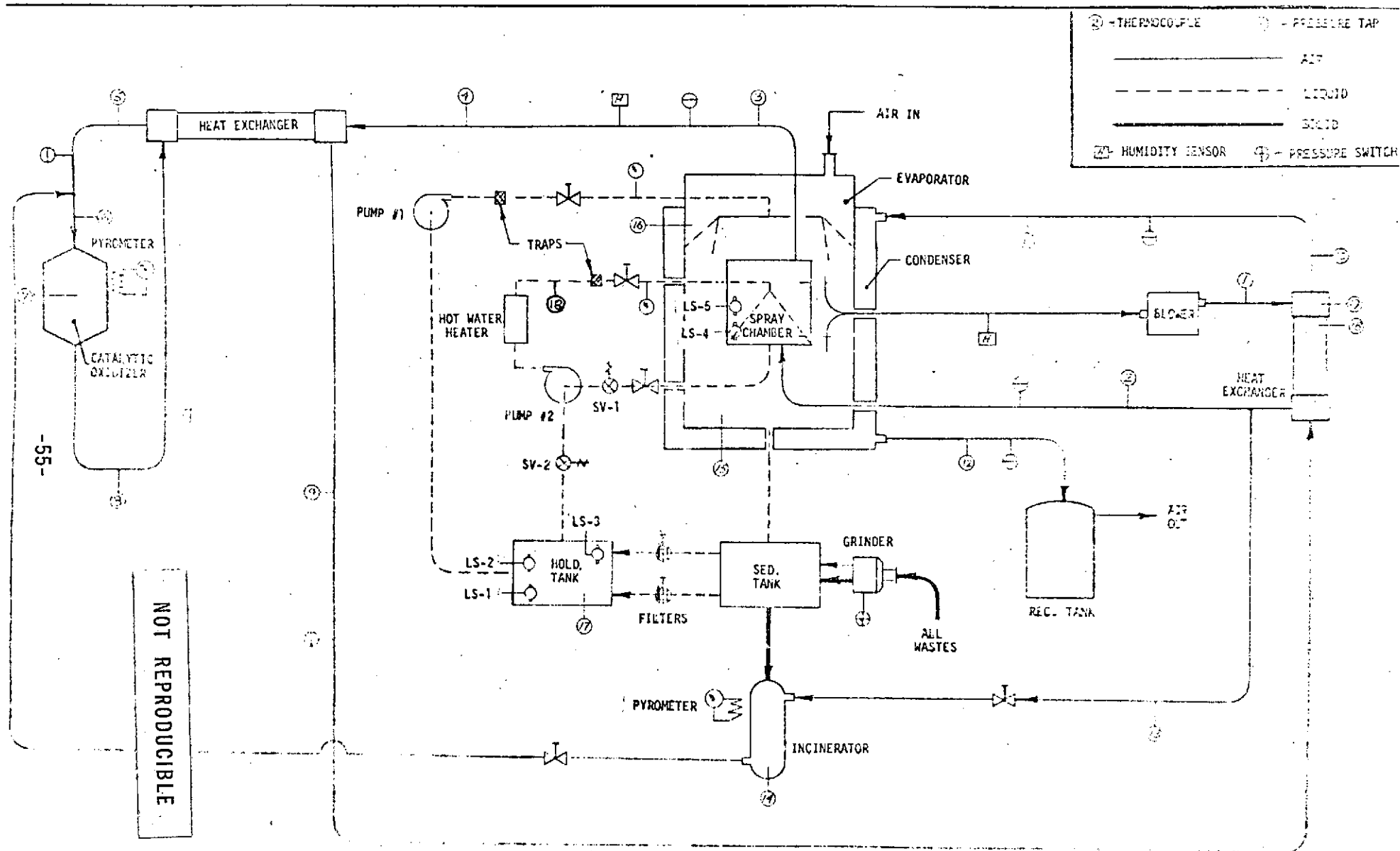


FIGURE 5-5 WATER HEATER ADDITION

EVAPORATION RATE

AFTER HOT WATER HEATER ADDITION

1. THEORETICAL

OUTLET OF SPRAY CHAMBER = .1534 Kg H₂O/Kg AIR

INLET TO EVAPORATOR = .0085 Kg H₂O/Kg AIR

.1449 Kg H₂O/Kg AIR

$$1360 \frac{\ell}{\text{MIN}} \times 1.08 \times 10^{-3} \frac{\text{Kg AIR}}{\ell} \times 60 \frac{\text{MIN}}{\text{HR}} = 88.1 \frac{\text{Kg}}{\text{HR}} \text{ (192 LB/HR AIR)}$$

$$\frac{.1449 \text{ Kg H}_2\text{O}}{\text{Kg AIR}} \times 88.1 \frac{\text{Kg}}{\text{HR}} \text{ AIR} = 12.7 \text{ Kg/HR H}_2\text{O} \text{ (27.8 LB/HR H}_2\text{O)}$$

$$\text{RATE} = 12.7 \frac{\text{Kg}}{\text{HR}} \text{ H}_2\text{O} \times 24 \frac{\text{HR}}{\text{DAY}} \times 1 \frac{\ell}{\text{Kg}} = 3050 \ell/\text{DAY} \text{ (80 GAL/DAY)}$$

2. ACTUAL

$$11.05 \ell/\text{HR} \times 24 \frac{\text{HR}}{\text{DAY}} = 265 \ell/\text{DAY} \text{ (70 GAL/DAY)}$$

3. REQUIRED

$$246 \ell/\text{DAY} \text{ (65 GAL/DAY)}$$

FIGURE 5-6 EVAPORATION RATE

C O N D E N S A T I O N R A T E

AFTER HOT WATER HEATER ADDITION

1. THEORETICAL

OUTLET OF SPRAY CHAMBER = .1534 Kg H₂O/Kg AIR

OUTLET OF CONDENSER = .0960 Kg H₂O/Kg AIR

.0574 Kg H₂O/Kg AIR

$$.0574 \frac{\text{Kg H}_2\text{O}}{\text{Kg AIR}} \times 88.1 \frac{\text{Kg}}{\text{HR}} \text{ AIR} = 5.06 \frac{\text{Kg}}{\text{HR}} \text{ H}_2\text{O} \text{ (11.0 LB/HR H}_2\text{O)}$$

$$\text{RATE} = 5.06 \text{ Kg/HR H}_2\text{O} \times 24 \text{ HR/DAY} \times \frac{1 \ell}{\text{Kg}} = 121 \ell/\text{HR} \text{ (31.7 GAL/DAY)}$$

2. ACTUAL

$$.985 \ell/\text{HR} \times 24 \text{ HR/DAY} = 23.6 \ell/\text{DAY} \text{ (6.34 GAL/DAY)}$$

3. GOAL

$$80\% \times 246 \ell/\text{DAY} = 197 \ell/\text{DAY} \text{ (52 GAL/DAY)}$$

FIGURE 5-7 CONDENSATION RATE

Microbiological analysis of the affluent and effluent is summarized in Table 5-4. The chemical analysis performed on the affluent is shown in Table 5-5. A detailed chemical analysis was performed on the recovered water of test day #1 and is shown in Table 5-6 while a simplified analysis for recovered water of day #2 is shown in Table 5-7.

A gas sample taken at the outlet of the condenser was analyzed and the results are shown in Table 5-8. These compositions are well below those allowed by the USPHS 1962 Standards.

Table 5-9 compares the performance characteristics of the subsystem with and without the addition of the hot water heater. As indicated, addition of the hot water heater increased the evaporation rate by 116% and the condensation rate by 370% (19 ℓ /day increase). Although the power requirement increased by 12% the latent heat recovered doubled to 8.5% when the heater addition was made.

Chemical analysis of the recovered water of day #1 of the performance test is compared with the 1962 USPHS in Table 5-10. The comparison shows a low count of chloride, total solids, NO_3 and sulfate, while the flouride, chromium and iron counts were higher than the standards. Some rusting was detected in the condenser packet accounting for the high iron and chromium contents in the recovered water.

Table 5-11 chemically compares the affluent and effluent of the subsystem taken during performance test days #2 and #3. As shown, the system reduced the pH, ammonia, conductivity, and the total solids count of the affluent to approach potability of the recovered water (see Table 5-10 for potability standards).

SAMPLE ANALYSISRESULT

AFFLUENT
(RAW SEWAGE FROM
HUMAN WASTE)

TOTAL COUNT

GREATER THAN 1.4×10^6
PER ML

COLIFORM DETECTION

DETECTED IN LARGE NUMBERS
(MPN INDEX OF 2400 PER
100 ML)

INHIBITORY OR BACTERICIDAL
PROPERTY OF AFFLUENT

NONE EXHIBITED

EFFLUENT

TOTAL COUNT

NO DETECTABLE VIABLE

PLATE COUNT

MICROORGANISMS

MEMBRANE FILTER

COLIFORM DETECTION

NONE DETECTED WITH MPN
(10, 1, 0.1 ML IN 5 TUBES
EACH). TECHNIQUE

INHIBITORY OR BACTERICIDAL
PROPERTY OF EFFLUENT

NONE EXHIBITED POSITIVE
GROWTH WHEN $1/10^4$ DILUTION
OF AFFLUENT ADDED BACK

TABLE 5-4 MICROBIOLOGICAL ANALYSIS

TABLE 5-5 AFFLUENT CHEMICAL ANALYSIS

MATERIAL DESCRIPTION:

Analysis of Affluent Water Sample Before Processing (Day #1 - Performance Test)
8/19/73

TEST PROCEDURE:

Standard Methods

TEST RESULTS:

<u>Properties Tested</u>	<u>Results</u>
pH	7.40
Specific Conductivity	1503 MICROMHOS/CM
Ammonia - N	175 mg/l
Total Solids	1327.5 mg/l

NOT REPRODUCIBLE

TABLE 5-6 CHEMICAL ANALYSIS OF DAY #1 RECOVERED WATER

MATERIAL DESCRIPTION:

Analysis of Effluent Water Sampled - 8/19/73 (Day #1 - Performance Test)

TEST PROCEDURE:

Standard Methods for Examination of Water and Wastewater, 17th Ed., 1971.

TEST RESULTS:

	<u>Units</u>	<u>DWWS</u>
Specific Conductivity	micro mho/cm	670.0
Turbidity	Jackson	4.5
Color	Pt-Co	3.0
Odor	-----	1
pH	ph units	3.20
Fluoride	mg/l	7.0
Chloride		90.0
C.O.D.		9.0
Carbonate		-----
Suspended Solids		1.5
Total Solids		198.3
Detergents		0.005
Nitrate - No3		4.15
Nitrate - N		0.95
Nitrite - N		0.055
Selenium		0.01
Sulfate		1.0
Ammonia - N		1.75
Arsenic		ND < 0.002
Barium		0.2
Boron		0.01
Cadmium		ND < 0.002
Chromium		0.4
Copper		0.3
Ruthenium		0.02
Silver		0.0008
Iron		20.3
Lead		ND < 0.0008
Manganese		0.001
Mercury		ND < 0.002
Nickel		0.8
Zinc		0.02

NOT REPRODUCIBLE

TABLE 5-7 CHEMICAL ANALYSIS OF DAY #2 & 3 RECOVERED WATER

MATERIAL DESCRIPTION:

Analysis of Effluent Water Sample 8/20/73 and 8/21/73 (Day #2 and #3 Combined Performance Test)

TEST PROCEDURE:

Standard Method

TEST RESULTS:

<u>Properties Tested</u>	<u>Results</u>
pH	3.00
Conductivity	630 micro mhos/cm
Ammonia-N	3.5 mg/l
Total Solids	243.7 mg/l

TABLE 5.8 OUTPUT GAS ANALYSIS

REQUESTOR T. Gresko - M2101					
S. O. No.			DATE		
MATERIAL DESCRIPTION: DWTS GAS SAMPLE FROM THE HOUSEHOLD WATER SYSTEM (8/20/73)					
TEST PROCEDURE: MASS SPECTROMETRIC ANALYSIS					
TEST RESULTS:					
<u>H₂</u>	<u>CH₂</u>	<u>CH₄</u>	<u>NH₃</u>	<u>H₂O</u>	<u>CO</u>
4.1%	--	--	--	44.1%	0.9%
<u>C₂H₄</u>	<u>NO</u>	<u>CO₂</u>	<u>NO₂</u>	<u>SO</u>	<u>SO₂</u>
--	--	51.1%	--	--	--
<div style="border: 1px solid black; display: inline-block; padding: 10px 20px;">NOT REPRODUCIBLE</div>					
COPIES:					
A. Tweedie - U2439			H. Thompson - U2439		
WORK PERFORMED BY:				APPROVED BY:	
R. Law					

TABLE 5-9. PERFORMANCE COMPARISON

	<u>PERFORMANCE TEST</u>	<u>WATER HEATER ADDITION</u>	<u>% INCREASE</u>
Evaporator Rate	102.5 ℓ /Day (27 Gal/Day)	265 ℓ /Day (70 Gal/Day)	116
Condensor Rate	5.15 ℓ /Day (1.35 Gal/Day)	23.6 ℓ /Day (6.34 Gal/Day)	370
AVE Power Requirement	3,437 Watts	3,857 Watts	12
Latent Heat Recovered	4.5%	8.5%	4%

TABLE 5-10 RECOVERED WATER COMPARISON

MATERIAL DESCRIPTION:

Analysis of DWMTS Water Sampled - 8/19/73

TEST PROCEDURE:

Standard Methods for Examination of Water and Wastewater, 17th Ed., 1971.

TEST RESULTS:

	<u>Units</u>	<u>DWMTS</u>	<u>USPHS</u>
Specific Conductivity	micro mho/cm	670.0	-----
Turbidity	Jackson	4.5	5
Color	Pt-Co	3.0	15
Odor	-----	1	3
pH	ph units	3.20	-----
Fluoride	mg/l	7.0	3.4
Chloride		90.0	250
C.O.D.		9.0	-----
Carbonate		-----	-----
Suspended Solids		1.5	-----
Total Solids		198.3	500.0
Detergents		0.005	-----
Nitrate - No3		4.15	45
Nitrate - N		0.95	-----
Nitrite - N		0.055	-----
Selenium		0.01	0.01
Sulfate		1.0	250
Ammonia - N		1.75	-----
Arsenic		ND < 0.002	0.05
Barium		0.2	1.0
Boron		0.01	-----
Cadmium		ND < 0.002	0.01
Chromium		0.4	0.05
Copper		0.3	1.5
Ruthenium		0.02	-----
Silver		0.0008	0.05
Iron		20.3	0.3
Lead		ND < 0.0008	0.05
Manganese		0.001	0.05
Mercury		ND < 0.002	-----
Nickle		0.8	-----
Zinc		0.02	5.0

NOT REPRODUCIBLE

TABLE 5-11. CHEMICAL COMPARISON OF AFFLUENT AND EFFLUENT OF DAY 8/20 and 8/21/73

<u>PROPERTY</u>	<u>AFFLUENT</u>	<u>EFFLUENT</u>
pH	7.40	3.00
Specific Conductivity	1503 MICROMHOS/CM	630 MICROMHOS/CM
Ammonia-N	175 mg/ℓ	3.5 mg/ℓ
Total Solids	1327.5 mg/ℓ	243.7 mg/ℓ

6.0 CONCLUSIONS

The Domestic Water and Waste Treatment Subsystem attained the required evaporation rate of 246 ℓ /day (65 gal/day). The large power requirement (3.8 Kw ave.) was due to the absence of latent heat transfer across the evaporator/condenser walls. Subsystem design was based on an anticipated 84% of liquid evaporation to be supplied by latent heat transfer, while the other 16% provided by air evaporation. However, system tests showed that only 8% of the liquid was evaporated by latent heat transfer therefore requiring the balance of the requirement to be met by air evaporation.

Since condensation rates relied solely on the latent heat transfer, the requirements could not be reached. It was believed that a thick boundary layer of air lying stagnant along the condenser walls hindered any heat transfer. These rates could be increased by availing more heat transfer surface area between the evaporator and condenser (larger packeted tank) or by increasing the velocity of the airflow inside the existing condenser packet. However, power requirements would increase since addition of a recirculating blower in a single loop with the condenser would be required.

The subsystem effectively reduced biological and chemical impurities from the affluent to approach the USPHS standards for drinking water. Also, many gases output from the system were below any pollution codes now available.

Economic feasibility of the subsystem depended upon the evaporator/condenser assembly to transfer large amounts of latent heat in order to reduce electric power required to evaporate the waste liquids. It is possible that these requirements could be reduced by compacting the total system inside the evaporator/condenser so that any heat leaks would enter the spray chamber and complement evaporation.

References

1. "Wastewater Engineering Collection, Treatment, Disposals" - Mitclaf -
Edy Inc. - P 651 - McGraw-Hill 1972.
2. "Water Recovery and Solid Waste Processing for Aerospace and Domestic
Applications" - Interim Report - P 2-14 1972.

THE FOLLOWING PAGES ARE DUPLICATES OF
ILLUSTRATIONS APPEARING ELSEWHERE IN THIS
REPORT. THEY HAVE BEEN REPRODUCED HERE BY
A DIFFERENT METHOD TO PROVIDE BETTER DETAIL